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CORUNDUM AND THE PERIDOTITES OF WESTERN NORTH CAROLINA

BY

JOSEPH HYDE PRATT AND JOSEPH VOLNEY LEWIS

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NORTH CAROLINA GEOLOGICAL SURVEY

J. A. HOLMES, STATE GEOLOGIST

VOLUME I

CORUNDUM AND THE PERIDOTITES OF WESTERN NORTH CAROLINA

BY

JOSEPH HYDE PRATT

AND

JOSEPH VOLNEY LEWIS

RALEIGH
NORTH CAROLINA
1905

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LETTER OF TRANSMITTAL

Chapel Hill, N. C., April 1, 1905.

To His Excellency, Hon. R. B. Glenn,
Governor of North Carolina.

Sir—I have the honor to submit for publication as Volume I of the Reports of the North Carolina Geological Survey, a description of the Corundum and the Peridotite Deposits of Western North Carolina, prepared by Dr. Joseph Hyde Pratt, of the Survey, and Professor Joseph Volney Lewis, formerly of the Survey, but now of Rutgers College, New Jersey.

The Survey has heretofore limited its publications to a series of smaller preliminary reports in the form of Bulletins and Economic Papers, embodying the immediate results of its investigations. The volume now being published is the first of a series of more elaborate reports which will embody, as far as practicable, the results of the maturer investigations relating to one or more special subjects.

With great respect,
Yours truly,
J. A. Holmes,
State Geologist.

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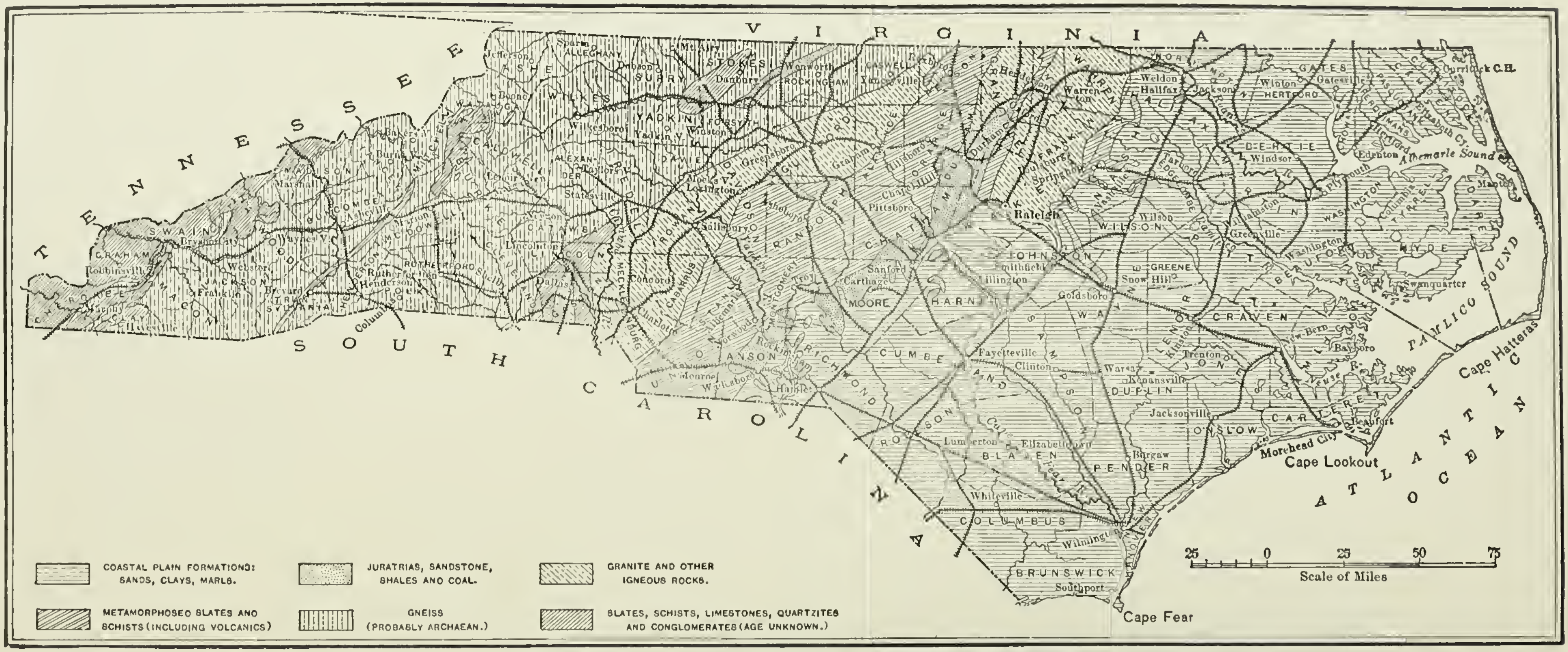
PREFACE

In the following report the authors have endeavored to describe as fully as possible the geology, petrology, and mineralogy of the belt of corundum-bearing rocks in western North Carolina, so far as these are known at the present time. Since the publication in 1896 of Bulletin No. 11, on Corundum and the Basic Magnesian Rocks of Western North Carolina, the study of this region has been continued at intervals during portions of each year. One or the other of the authors has visited and examined every known occurrence of peridotite in North Carolina. They have also visited for comparison many more or less similar occurrences in other eastern States and a few localities in the western States and in Canada. Both the authors have visited repeatedly and have carefully studied all the more important corundum localities in North Carolina during various stages of prospecting and mining work of the past several years. In the investigation of corundum and the associated minerals as described in chapters VI, IX, X, and XII, the work has been conducted mainly by Dr. Pratt; while the study of the associated rocks described in chapters II, III, IV, and V has been chiefly the work of Professor Lewis. In the preparation of this report, however, each author has repeatedly gone over the other's work for the purpose of criticism and revision; and hence even the chapters named are largely a joint production, while other parts of the report are even more fully the result of collaboration.

To only a limited extent have the authors been able to carry on field work together. This work, for the most part, has been done at different times, each working independently. Notwithstanding this fact and the somewhat different methods employed, each has been led to essentially the same conclusions in the interpretation of field observation. Especially is this true of the theories of the origin and present relations of both the rocks and the minerals. A notable instance is the explanation of the origin of the corundum in association with basic magnesian rocks. In this case, practically the same conclusions were arrived at independently by the one from the investigation of corundum deposits in the peridotites and by the other from a petrographic study of the corundum-bearing amphibolites and anorthosites.

Special acknowledgments are due to the late Dr. Geo. H. Williams for assistance and suggestions in the early stages of the field work; to Hon. Chas. D. Walcott for many courtesies extended in the laboratories and library of the U. S. Geological Survey; to Professors S. L. Penfield and L. V. Pirsson for similar courtesies in their laboratories at Yale University, as well as for assistance and suggestions in portions of the work; to Mr. Arthur Keith, of the U. S. Geological Survey, for assistance and criticism in the preparation of the geological map of western North Carolina; to the late Dr. H. S. Lucas, Messrs. Chas. N. Jenks, Geo. Bidwell, W. E. Hidden, and L. S. Ropes for many courtesies and valuable assistance in the prosecution of the field work; and to Mr. R. Henry Scadin for photographic work. In the final preparation of the manuscript for publication, valuable editorial services were rendered by Mr. Geo. M. Wood, of the Editorial Division of the U. S. Geological Survey.

J. A. Holmes,
State Geologist.


VIRGINIA
TENNESSEE
SOUTH CAROLINA
ATLANTIC OCEAN
PAMLICO SOUND
Albemarle Sound
Cape Hatteras
Cape Lookout
Cape Fear
Raleigh
Wilmington
Fayetteville
Greensboro
Salisbury
Charlotte
Asheville
Goldsboro
New Bern
Morehead City
Beaufort
Edenton
Weldon
Southport
25 0 25 50 75
Scale of Miles
COASTAL PLAIN FORMATIONS: SANDS, CLAYS, MARLS.
JURATRIAS, SANDSTONE, SHALES AND COAL.
GRANITE AND OTHER IGNEOUS ROCKS.
METAMORPHOSED SLATES AND SCHISTS (INCLUDING VOLCANICS)
GNEISS (PROBABLY ARCHAEAN.)
SLATES, SCHISTS, LIMESTONES, QUARTZITES AND CONGLOMERATES (AGE UNKNOWN.)

SKETCH MAP OF NORTH CAROLINA, SHOWING THE DISTRIBUTION OF THE PRINCIPAL GEOLOGIC FORMATIONS.

CORUNDUM AND THE PERIDOTITES OF WESTERN NORTH CAROLINA.

By Joseph Hyde Pratt and J. Volney Lewis.

CHAPTER I.

THE CORUNDUM BELT OF NORTH CAROLINA.

GENERAL GEOLOGY OF THE STATE.

In crossing the State of North Carolina from the seacoast to its western boundary, about half the distance is traversed through a region which is very nearly level or gently undulating. The surface of this portion, the coastal plain, is covered with sandy and loamy soils, hard rocks being almost entirely absent. Immediately west of this region is the Piedmont plateau, whose surface becomes more and more hilly westward until the mountains of the Blue Ridge are encountered, and these and other mountain ridges and valleys constitute the remaining western portion of the State. In the Piedmont and mountain regions the soil is underlain by hard granitic and slaty rocks. The geologic formations of the eastern half of the State are radically different from those of the central and western portions, but most of the rocks of the Piedmont plateau are very similar to those of the mountain district; and hence these latter divisions are based on physiographic rather than geologic character.

These regions constitute the three great physiographic divisions of the State, which have been designated the coastal plain, the Piedmont plateau, and the mountain region, respectively, and their boundaries are generally rather sharply defined. The rock formations of these contiguous regions (Pl. I) are widely separated in age, those covering the coastal plain being among the most recent, while those of the Piedmont plateau and mountains are doubtless largely to be classed among the oldest formations known. An exception to this is found in the limited areas of Triassic red sandstones and shales.

The coastal plain, as indicated above, represents the most recent geologic formations, composed chiefly of unconsolidated gravels, sands, clays, and marls, arranged in nearly horizontal layers, with the finer material, in general, nearer the coast. Along its eastern border this region contains sounds and bays, sand dunes and ridges, swamps and marshes, and other features that are characteristic of a seashore area. Farther inland it is gently undulating and has more upland and less marsh; and toward its western boundary the swamps disappear almost entirely, the upland predominates, and the surface becomes more undulating and, in places, even hilly. The soils toward the east are composed of fine sand and silt, but nearer the western border they contain a larger proportion of coarse sand and gravel mingled with clay. This region extends from Raleigh eastward to the coast, and its western boundary, roughly defined, runs from the western part of Warren through Franklin, Wake, Chatham, Moore, Montgomery, and Anson counties.

Along the western border of the coastal plain occasional outcrops of hard granites and slates occur in the beds of streams, where the once overlying sands and clays have been washed away. In the southeastern counties of this region some of the formations contain consolidated limestone, which is exposed at the surface along the banks of streams at many localities. This rock is of such quality at some places that it can be used for making lime, for macadamizing roads, and perhaps in some cases for building purposes.

The Piedmont plateau, extending westward from the coastal plain to the mountains, is about 125 miles wide and has an average elevation approximating 800 feet. Crossing this Piedmont plateau obliquely is a series of geologic formations which are, in their general trend, parallel to the mountains and the seashore. The most eastern of these formations is a narrow belt of Triassic sandstone and shales which has a maximum width of about 15 miles, and extends from Oxford, in Granville County, southward through portions of Wake, Durham, Chatham, Moore, Montgomery, Richmond, and Anson counties, and across the State line into South Carolina. It is in these formations that the coal deposits of Chatham and Moore counties, and the available beds of red, gray, and brown sandstone have been found. Northeast of this sandstone, and between it and the coastal plain, there are considerable areas of granite that extend across portions of Wake, Franklin, Warren, Vance and Granville counties. To the west is a formation of metamorphosed slates and schists which crosses through Person, Durham, Orange, Chatham, Randolph, Davidson, Montgomery, Stanley, Union, and Anson counties, and has a general width of from 20 to 40 miles. Just west of this formation there is an area of granites, and between these and the mountain regions are gneisses, considered of pre-Cambrian age. Near the western boundary of the Piedmont plateau is another Triassic sandstone belt, much more limited in area than the one of the east, which extends from the Virginia line across portions of Rockingham and Stokes counties, with a maximum width of from 4 to 5 miles.

The mountain region (Pl. II) includes the Blue Ridge, the Great Smoky Mountains, and the country between, which is occupied by numerous irregular ranges, often separated by narrow valleys and deep gorges. The average elevation of this region is about 2,700 feet above sea level, but the summits of many ridges are over 5,000 feet, and a considerable number of peaks reach a height of more than 6,000 feet. The highest of these is Mount Mitchell, with an elevation of 6,711 feet. Over the larger part of this region are to be found the older crystalline rocks, largely gneisses and granites, which are continuous with those of the western part of the Piedmont plateau, and, like these, are considered of pre-Cambrian age. These rocks are often greatly folded and faulted and extreme metamorphism has frequently obscured or completely obliterated all traces of their original character. On the western and eastern borders of this mountain region, approximately along the line of the Blue Ridge and Great Smokies, are two narrow belts of younger rocks consisting of limestones, sandstones, shales, and conglomerates, and their metamorphic equivalents, crystalline limestones, slates, and quartzites. These rocks contain no fossils, and were formerly designated as the Ocoee formation, of undetermined age; but more recently Mr. Arthur Keith, of the U. S. Geological Survey, has correlated them with the lower Cambrian. In this region, as in the Piedmont plateau, the rocks are decayed to a considerable extent and thus have produced deep soils, which vary in character according to the rocks from which they have been formed. The soils are for the most part porous and fertile and support a luxuriant vegetation, the slopes of the mountains being covered in many places by heavy virgin forests. Where the rocks contain a large proportion of feldspars or other aluminous minerals, the resulting soils are predominantly clayey. Such soils characterize a large part of both the Piedmont and mountain regions.

GEOLOGY OF THE CORUNDUM BELT.

Corundum has been found in both the Piedmont and the mountain regions but it is in the latter that the "corundum belt" proper is located. The corundum that has been found in a few localities of the Piedmont region occurs for the most part in amphibolite dikes cutting the gneisses of Alexander and Iredell counties.

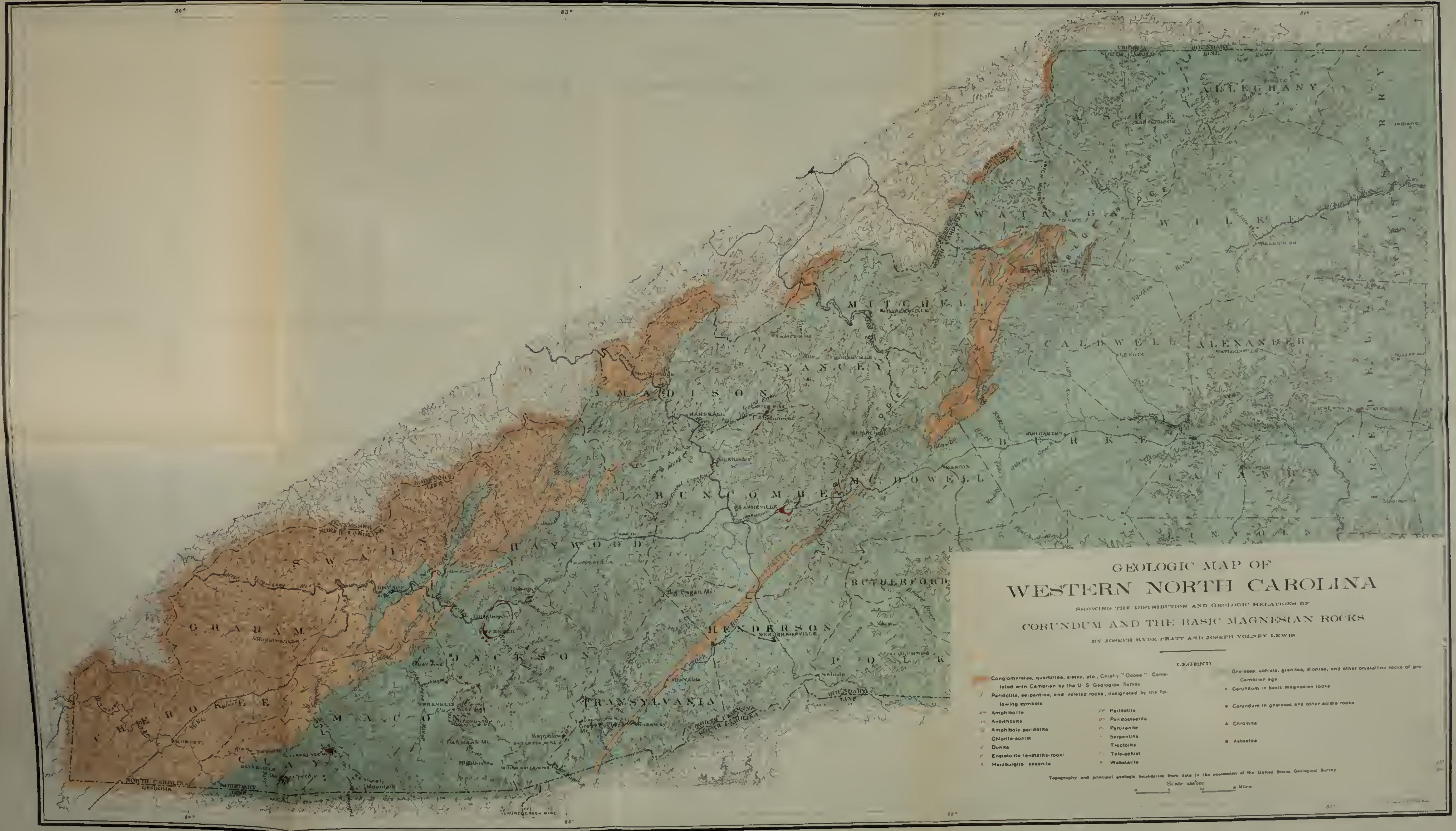
The corundum belt occupies a broad band of gneisses of the mountain region and extends from the Georgia line through Clay, Macon, Transylvania, Jackson, Haywood, Buncombe, Madison, Yancey, and Mitchell counties. The larger quantity of the corundum is associated with basic magnesian rocks known as peridotites (see Chapter II), but smaller amounts occur in amphibolite dikes and also in the gneisses and schists. The continuation of these peridotites extends the belt through Watauga, Ashe, and Alleghany counties into Virginia, although corundum has not been found in this portion of the belt north of Mitchell County.

The mountain and Piedmont regions of North Carolina are but a portion of the great belt of crystalline rocks that is coextensive with the Appalachain mountain system. On account of their complex structure, and highly crystalline character, these rocks are generally considered to be of Archean age. The southern extremity of this belt disappears beneath the younger formations in central Alabama. The principal constituent of this system is banded gneiss, which includes many masses of granitic and other distinctly igneous rocks, and which often, through higher development of lamination, passes into mica-schists and amphibole-schists.

The gneisses have been usually considered, in part, sedimentary rocks that have lost their original characteristics (with the possible exception of bedding in some cases) in the great earth movements and other metamorphosing agencies to which they have been subjected. Some of them are undoubtedly granites, diorites, and other igneous rocks that have been sheared or squeezed by the same agencies, and transitions from the massive to the laminated forms have often been observed.

Lamination is often developed where no such original structure existed, as in the sheared massive rocks referred to above. It is known that such structure produced by movement in the mass of the rock may, and often does, obliterate whatever original structure may have been present; so that a sedimentary rock thus mechanically laminated and at the same time thoroughly crystallized would no longer show its original stratification. The new structural planes may in certain cases correspond with bedding, but often they do not; and it is frequently impossible even to distinguish between gneisses and schists of igneous origin and those produced by the extreme metamorphism of sedimentary beds. The strikes and dips observed in this region are in all cases those of secondary lamination planes, and have no reference to stratification nor to any particular theory of origin.

In some regions the gneisses present several characters that point strongly to a sedimentary origin. They contain limestones in considerable amount at the forks of Caney Fork of Tuckaseegee River, in Jackson County, and on the eastern slopes of Onion Mountain and the headwaters



GEOLOGIC MAP OF
WESTERN NORTH CAROLINA
SHOWING THE DISTRIBUTION AND GEOLOGIC RELATIONS OF
CORUNDUM AND THE BASIC MAGNESIAN ROCKS
BY JOSEPH HYDE PRATT AND JOSEPH VOLNEY LEWIS

of Ellijay Creek, in Macon County. These limestones are often more or less graphitic. There are also frequent streaks and disseminated scales of graphite in the mica-schists, as noted in several localities of corundum-bearing schists described in Chapter VII. These, together with the extremely variable character of the gneisses in many regions, and their frequent rapid passing into mica-schists and sometimes into quartz-schists, would seem to justify the reference of a large part of the series to a sedimentary origin.

The prevailing strike of the lamination planes in the gneiss of western North Carolina is about N. 30° E., and the prevailing dip is at a high angle toward the southeast. Very frequently local variations occur, especially in the dip, and often the prevailing southeasterly dip will become vertical within an outcrop covering only a few feet and, tipping over, will pass into a northwesterly dip. All stages occur from these local variations in the dip and strike to the most complex gnarled and contorted forms. (Pl. III, A and B). In general, the lamination has suffered most deformation in the immediate vicinity of igneous intrusions and the forces that produced the contortions doubtless formed simultaneously the fissures into which the massive rocks were injected.

This gneissic belt of the mountain region is, as was stated above, bordered on the west and east by two belts of partially metamorphosed sedimentary rocks (Ocoee) that are considered by Mr. Arthur Keith, of the U. S. Geological Survey, to be of lower Cambrian age. No distinct fossils have been found in this formation, and its structure is greatly complicated by the orogenic disturbances in which this region has been repeatedly involved. This formation consists of a lower series of sandstones and conglomerates and an upper series of shales and limestones, the whole lying uncomformably on the gneisses.

The broader of these two belts lies along the Tennessee border and extends with an irregular outline northward to a point a little south of Johnson City, Tennessee, crossing through Cherokee, Clay, Graham, Swain, Haywood and Madison counties, North Carolina. Another and much narrower belt lies about 40 miles east of this, but on account of the irregular boundaries the two belts are in some places not more than 25 miles apart. This narrow belt extends northeastward from the headwaters of the upper French Broad River, approximately parallel to the Blue Ridge, crossing through Transylvania, Henderson, McDowell, Yancey, Burke, Mitchell, Caldwell, and Watauga counties.

The gneisses that lie between these two belts are cut by a great many narrow strips and small lenticular masses of basic magnesian rocks, chiefly peridotites, which rarely exceed a mile or two in length. As far as has been observed, these rocks are nowhere intimately associated with igneous rocks of the granitic type. Contortions have been observed, however, in the adjacent gneisses similar to those in the vicinity of granites, and often a local transition to mica-schist gives evidence of an unusual amount of movement. These basic magnesian rocks in North Carolina intersect no formations of later age than the supposedly pre-Cambrian gneisses.

The peridotites and related rocks form disconnected masses arranged in a line or series of parallel lines that coincide approximately in direction with the strike of the gneissic lamination. They almost invariably have a sheath of some schistose mineral developed along their borders, so that there is rarely an absolute contact between them and the normal gneiss.

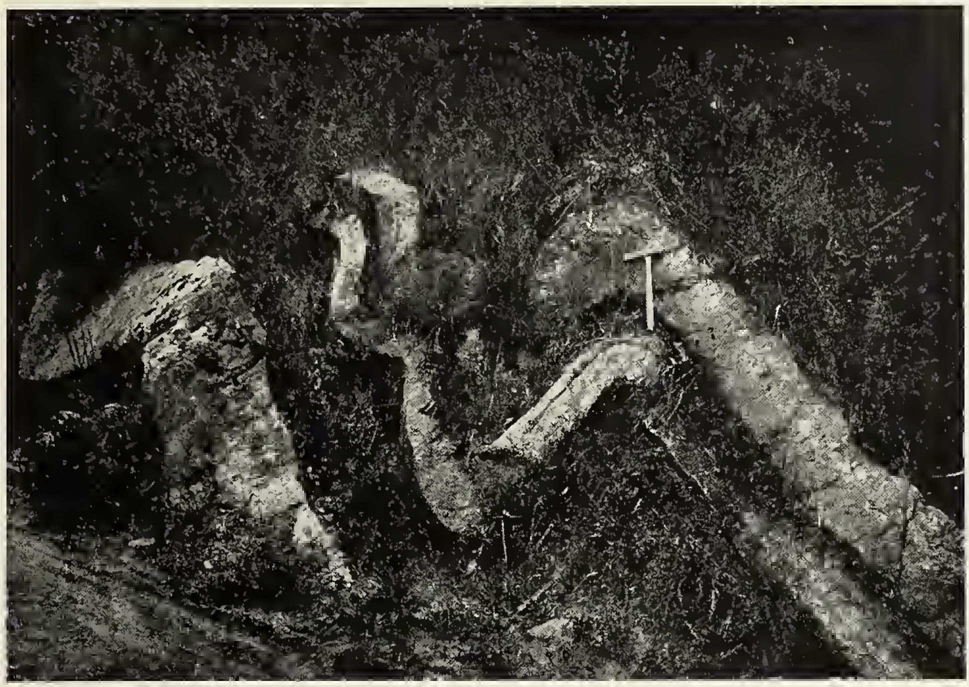
These basic magnesian rocks occupy but a small portion of the gneissic belt; but it is in association with them that the greater part of the corundum has been found, and hence the region in which they occur is generally known as the *corundum belt.*.

The map (Pl. II) shows the relation of the Paleozoic formations to the crystalline rocks, also the distribution of the peridotites and pyroxenites and the very small area that they occupy in the crystalline belt. It has been necessary, for the sake of clearness, to exaggerate in some cases the areal proportions of these rocks. This is especially true of the talc- and chlorite-schists, which seldom attain a width of more than 20 to 30 feet in outcrop.

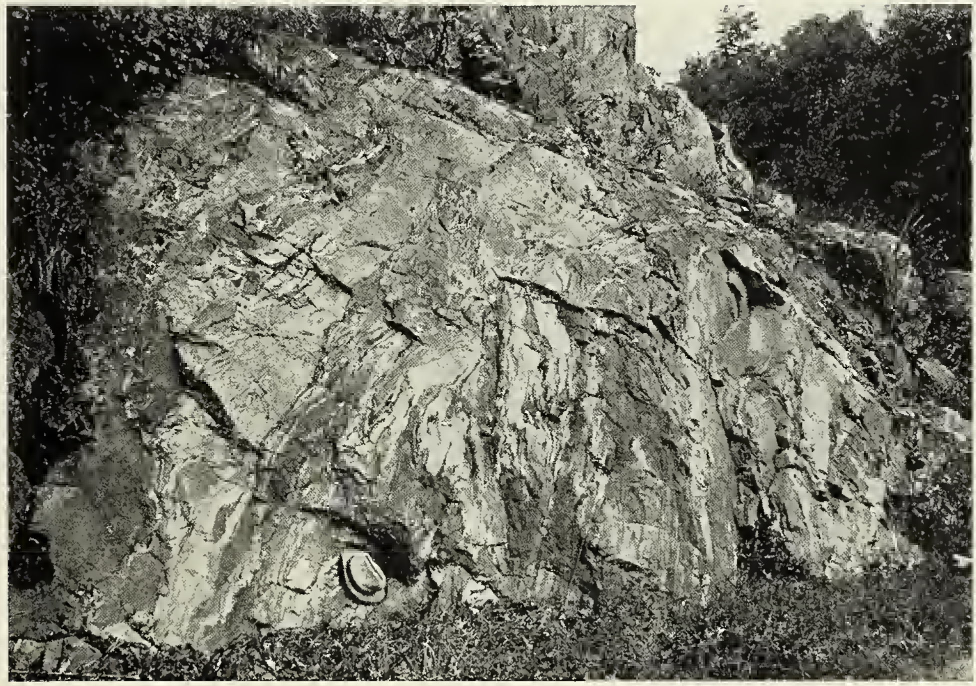
ROCKS OF THE CORUNDUM BELT.

The rocks that are of most importance in the corundum belt are chiefly peridotites, since it is in association with these that most of the corundum in North Carolina has been found. Of the peridotites, dunite, harzburgite (saxonite), amphibole-peridotite, and troctolite have been identified. The secondary and schistose rocks associated with these are chiefly serpentine, talc-schist, and chlorite-schist. Besides these, there are dikes of amphibolite intimately associated with the peridotites and more rarely, pyroxenite, gabbro, and diorite. The modes of occurrence, petrography, and distribution of these rocks are fully described in the following chapters.

The rocks of the gneissic belt in which these basic magnesian rocks occur consist chiefly of fine-grained, light gray gneiss composed of both orthoclase and plagioclase feldspars in abundance, muscovite and biotite in variable proportions, and a smaller amount of quartz. By a relative decrease in the feldspars and an increase in the micas, the rock frequently passes into mica-schist, in which both micas usually occur, though one often predominates to the almost total exclusion of the other. The



A, FOLDED GNEISS, SANDYMUSH CREEK, BUNCOMBE COUNTY, N. C.



B, CONTORTED GNEISS, FRENCH BROAD RIVER, NEAR ALEXANDER, BUNCOMBE COUNTY, N. C.

occasional occurrence of considerable quantities of dark-green amphibole in both phases of the rock gives rise to the corresponding varieties, amphibole-gneiss and amphibole-schist. In these rocks the micas are either absent or are insignificant in amount. In general, the hornblendic varieties constitute but a subordinate part of the gneissic formation in the vicinity of the peridotites, but their greater resistance to weathering causes them to appear frequently in outcrops and in loose surface fragments, and may easily lead to an exaggerated estimate of their importance, as was frequently the case in the earlier observations of these rocks. More rarely a variety of mica-schist is encountered in which quartz greatly predominates, giving rise to local developments of quartz-schist.

In several places the rocks of the gneissic belt are themselves found to be corundum-bearing in places where no genetic relationship with the basic magnesian rocks can be observed. Thus, corundum is found in gneiss, mica-schist, amphibole-schist, and quartz-schist in addition to the basic magnesian rocks. Brief descriptions of the peculiarities of these various modes of occurrence will be found in Chapter VII.

CHAPTER II.

THE PERIDOTITES AND ASSOCIATED BASIC MAGNESIAN ROCKS.

CLASSIFICATION.

The association of peridotites, pyroxenites, amphibolites, diorites, and gabbros, is remarkably persistent throughout the length of the Appalachian crystalline belt of the United States, and continues through the eastern provinces of Quebec to Newfoundland. By bringing together the numerous isolated observations and studies that have been made in various parts of this vast territory during the past two or three decades, this association is clearly recognized.

The close relationship of these rocks, both chemically and geologically, has been recognized by all who have had occasion to study them in any part of the region. It has remained for later petrographic studies, however, to determine their true character as igneous intrusives in many localities; and it is now manifest that all the points of resemblance in composition, modes of occurrence, etc., are to be regarded as but manifestations of their genetic unity. The rocks are unquestionably of igneous origin, and, in the light of present knowledge, are to be regarded as products of the differentiation of one original magma (see Chapter V).

The prevalent type of this basic crystalline series in western North Carolina is peridotite; this is also true of these rocks in Georgia, of large areas in Quebec, and of areas elsewhere. The gabbros and diorites preponderate in Maryland and Delaware, the pyroxenites in Pennsylvania, and so on; but the actual association for any considerable area in one part of the belt is practically the same as that for any other.

Systematic petrographers often classify the peridotites as subordinate facies of gabbro; but in North Carolina and in some other portions of the belt this relation is reversed—the gabbros occur only in small masses, forming insignificant local facies of the peridotites. Furthermore, these olivine rocks, although usually occurring in comparatively small, disconnected areas, appear at short intervals in the midst of the acid gneisses and crystalline schists throughout a belt more than 2,000 miles long. These considerations are regarded as sufficient grounds for grouping the peridotites in a separate family, coördinate in rank with the gabbros and diorites. For similar reasons, the same standing is accorded to the pyroxenites and amphibolites.

Owing to the extensive alterations that many of these rocks have undergone, they naturally group themselves, first of all, into primary and secondary rocks.

PRIMARY ROCKS.

The primary rocks are allotriomorphic rocks of granitoid texture, and may be classified in the order of increasing lime and alumina and, in general, decreasing magnesia, as follows:

- Peridotites.
  - Dunite.
  - Harzburgite (Saxonite).
  - Amphibole-peridotite.
  - Troctolite (in part).
- Pyroxenites.
  - Enstatolite (enstatite rock).
  - Bronzitite.
  - Hypersthenite.
  - Websterite.
- Gabbroic rocks.
  - Troctolite (in part).
  - Olivine-gabbro.
  - Gabbro.
  - Anorthosite (in part).
- Amphibolite.[1]
- Dioritic rocks.[1]
  - Mica-diorite.
  - Diorite.
  - Anorthosite (in part).

PERIDOTITE.

The following members of the peridotite family, essentially olivine rocks, have been recognized in greater or less abundance in various parts of western North Carolina:

Dunite, essentially the pure olivine rock, with accessory chromite or picotite, is by far the most abundant rock of the magnesian series in this region.

Harzburgite (saxonite), olivine-enstatite rock, forms important masses at several localities.

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[1] Some of the amphibolites and diorites are paramorphic derivatives of the corresponding pyroxene rocks (p. 161), and should, of course, be classed as secondary. There is reason to believe that many, if not all, of these rocks are of this nature; but in the absence of positive evidence in many cases, and because they possess, in part, the massive granular character of primary rocks, they are included here.

Amphibole-peridotite, composed of olivine and green amphibole, is also important at a few places.

Troctolite (*Forellenstein, ossipyte*), olivine-anorthite rock, occurs as a minor facies of the peridotite in small areas at several localities. By the introduction of augite it passes into olivine-gabbro.

PYROXENITE.

In 1890 Dr. George H. Williams first proposed the recognition of the massive pyroxene rocks as a distinct family, to be known as *pyroxenites.*[2] In this family he placed bronzitite, hypersthenite, and diallagite, which had been previously described, and proposed the name websterite for the newly discovered member composed of both orthorhombic and monoclinic pyroxenes. Rosenbusch[3] notes that diopsidite and augitite have also been described.

The chief pyroxenite in the peridotite belt of North Carolina, however, being composed essentially of light-gray enstatite, does not correspond to any of the above types. It is often erroneously called anthophyllite rock, and was first recognized as a pyroxenite in Bull. No. 11 of this Survey, under the name *enstatite rock.* In the interest of uniformity, it is now proposed to recast this term into the form *enstatolite,* with the obvious derivation from the Greek ενστατης and λιθος

The position of this rock in the pyroxenite family is shown by the following table, in which the members naturally fall into three groups, which may be called ortho-, clino-, and binary pyroxenites, according as orthorhombic or monoclinic pyroxenes, or both, are essential constituents of the rock:

PYROXENITE FAMILY.

Orthopyroxenite.		*Clinopyroxenite.*
Enstatolite.		Diopsidite.
Bronzitite.		Diallagite.
Hypersthenite.		Augitite.
	Binary pyroxenite.	
	Websterite.	

Four members of this family have been recognized in North Carolina, as follows:

Enstatolite (enstatite rock) is composed essentially and almost exclusively of the orthorhombic pyroxene, enstatite. Though by no means equal in importance to the peridotites in North Carolina, it is somewhat commonly found throughout the region and forms many masses of considerable extent.

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[2] Am. Geologist, VI, 1891, pp. 35-49.

[3] Mikr. Phys., 3d ed., 1896, p. 369.

Bronzitite, composed of the bronzite variety of enstatite, is of comparatively rare occurrence.

Hypersthenite, consisting chiefly of the highly ferriferous orthorhombic pyroxene, hypersthene, is also rare.

Websterite, containing both orthorhombic and monoclinic pyroxenes, is of considerable importance at Webster, and occurs in other parts of the Webster area, but has not been recognized elsewhere in North Carolina.

GABBROIC ROCKS.

Several facies of gabbroic, or augite-plagioclase rocks are distinguishable, ranging from troctolite to anorthosite, as follows:

Troctolite, as described above, occurs as a facies of olivine-gabbro with little or no augite, and forms a transition to the peridotites.

Olivine-gabbro has been found only as a minor transition facies.

Gabbro has been recognized with the peridotites on Buck Creek and Shooting Creek, altering into gabbro-diorite in a manner entirely analogous to that observed by Dr. George H. Williams[4] in the Maryland gabbros. By the introduction of olivine it passes into olivine-gabbro and troctolite, on the one hand, and by the loss of augite, into anorthosite on the other.

Anorthosite, essentially a plagioclase rock, is in North Carolina composed of anorthite, and occurs only as a minor facies of gabbro and diorite.

AMPHIBOLITE.

Amphibolite, consisting of a pale-green to grass-green and dark greenish black amphibole (edenite), is abundant in many localites in the southwest, particularly on Shooting Creek and Buck Creek and in the adjoining portions of Georgia. Most of it is more or less schistose in structure, and part, at least, is secondary after monoclinic pyroxenes. It frequently carries varying amounts of feldspar (anorthite), and by increase of this and decrease of the amphibole, it passes into diorite and anorthosite.

DIORITIC ROCKS.

Diorite occurs chiefly as a subordinate facies of amphibolite, but not in all cases; and like the amphibolite, is doubtless chiefly secondary.

Mica-diorite is composed of biotite, green amphibole, and plagioclase, and occurs in a dark, somewhat schistose intrusion with peridotites at the Hayes (Egypt) mine, in Yancey County.

Diorite, a hornblende-plagioclase facies of amphibolites, in many localitics forms a transition to anorthosite, though it sometimes occurs in considerable amount.

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[4] Bull. U. S. Geol. Survey, No. 28, 1886, pp. 40-49.

Anorthosite is similar in every way to the corresponding facies of gabbro, and if the diorites are to be considered as gabbro-diorites, is identical with them.

SECONDARY ROCKS.

The secondary rocks are readily divided into two groups, according as they have been derived from the corresponding primary rocks by anhydrous or hydrous modes of alteration.

Anhydrous:
- Gabbro-diorite.
  - Amphibole-gneiss.
- Pyroxenite-amphibolite.
- Peridotite-amphibolite.
  - Amphibole-schist.

Hydrous:
- Serpentine.
- Steatite (soapstone).
  - Talc-schist.
  - Peridosteatite.
- Chloritite (chlorite rock).
  - Chlorite-schist.

ANHYDROUS GROUP.

The anhydrous secondary rocks are chiefly paramorphic and dynamic derivations of the corresponding primary rocks. The exceptions to this are the peridotite-amphibolites, the production of which involves a loss of some of the constituents of the original peridotite (p. 125). The development of lamination produces the corresponding amphibole-schist.

Gabbro-diorite.—Gabbros in process of alteration to diorites by paramorphism of the augite into green amphibole were found associated with peridotites on both Shooting Creek and Buck Creek, in Clay County (pp. 71, 76). Just to what extent the diorites of this region have been derived in this way, it is impossible at present to say, but it seems highly probable that most of them are of this character.

Amphibole-gneiss (gabbro-diorite-gneiss) is simply the dynamic derivative of the gabbro-diorite, more or less lamination having been produced by pressure in the previously massive rock. Amphibole-gneisses accompany the peridotites at many localities, and most of them, perhaps all, are doubtless to be regarded as laminated gabbro-diorites.

Pyroxenite-amphibolite.—Amphibolites are found at Buck Creek which still contain large remnants of augite altering into green amphibole.

showing that part of the amphibolites, at least, are derived from the corresponding monoclinic pyroxene rock (clinopyroxenite), although none of the unaltered original rock has been found. Here, again, it is impossible to determine how much of the amphibolite of this region has had such an origin; but judging from the uniform characteristics of the rock, it seems highly probable that most of it should be placed in this class.

Peridotite-amphibolite.—A light-gray fibrous amphibolite has been produced in considerable quantities in some localities by the amphibolization of peridotite, or alteration of peridotite into the closely related amphiboles, anthophyllite, cummingtonite, and gedrite.

The greater part of the amphibole-schist that occurs in connection with the peridotites is composed of green amphibole, and bears the same relation to the pyroxenite-amphibolite, described above, that the amphibole-gneiss does to the gabbro-diorite; that is, the greater part of the amphibole-schist of this region is doubtless a sheared pyroxenite-amphibolite.

There is also an amphibole-schist, of local importance, corresponding to the amphibole-peridotite above, and consisting of light-gray fibrous amphibole, often more or less altered into talc. These two varieties might be distinguished by the somewhat cumbrous names, pyroxenite-amphibolite-schist and peridotite-amphibolite-schist.

HYDROUS GROUP.

The hydrous secondary rocks, consisting chiefly of the minerals, serpentine, talc, and chlorite, are rarely the pure mineralogical types that their names indicate. Most of them contain more or less of all these minerals, besides a number of others of less importance; but one usually greatly preponderates and gives character to the rock. They are the results of hydration of anhydrous primary or secondary rocks, accompanied by more or less transference of materials.

Serpentine.—In North Carolina the serpentine rock has been derived from peridotites; but in Pennsylvania large areas of similar rocks are derived from pyroxenites. The serpentine usually contains scales of talc and chlorite, sometimes in considerable amount, besides the accessory chromite of the original rock.

Steatite (*soapstone*), consisting of grayish or greenish talc, with more or less chlorite, is derived from peridotites, pyroxenites, and peridotite-amphibolites. Only a small proportion of the rock is massive, the greater part of it being more properly called talc-schist, which possesses a distinctly laminated character, and is sometimes highly fissile.

Peridosteatite[5] may be defined as an olivine-talc rock, or an olivine-steatite. The proportion of olivine varies greatly and talc usually preponderates. In some cases the talc is manifestly secondary after enstatite, and the rock might be called a meta-harzburgite.

Chloritite[6] (*chlorite rock*) consists of massive green felted scales of chlorite, with usually some talc, chromite, etc., and is derived from both peridotites and amphibolites. The massive form is less common than chlorite-schist, a laminated and sometimes highly fissile chlorite rock, in which most of the chlorite (and talc) scales are approximately parallel to the planes of lamination. Like the massive chloritite, this is derived from both peridotites and amphibolites, and occurs in great abundance in many parts of the peridotite belt.

DISTRIBUTION OF THE PERIDOTITES AND ASSOCIATED ROCKS IN EASTERN NORTH AMERICA.

A belt of peridotites and closely related basic magnesian rocks traverses the ancient crystalline gneisses and schists of eastern North America from east-central Alabama, 175 miles from the Gulf of Mexico, into the Gaspé Peninsula, on the Gulf of St. Lawrence, a distance of more than 1,600 miles; similar rocks again appear in western Newfoundland, thus extending the distance to more than 2,000 miles (see Pl. IV).

Beginning in Tallapoosa County, Alabama, where the gneisses and crystalline schists emerge from beneath the Cretaceous and later formations lying farther south, and passing northward one finds that small disconnected peridotite outcrops occur at short intervals, forming a narrow belt that extends approximately N. 50° E., passing near Atlanta, Asheville, Lynchburg, Washington, Baltimore, and Philadelphia, to Trenton, New Jersey, where the crystalline rocks again pass under the younger formations. With the reappearance of the crystallines at Hoboken, New Jersey, and on Staten Island, the peridotites are again represented by large masses of serpentine. A number of other outcrops of serpentine, and in some cases unaltered peridotites, occur through

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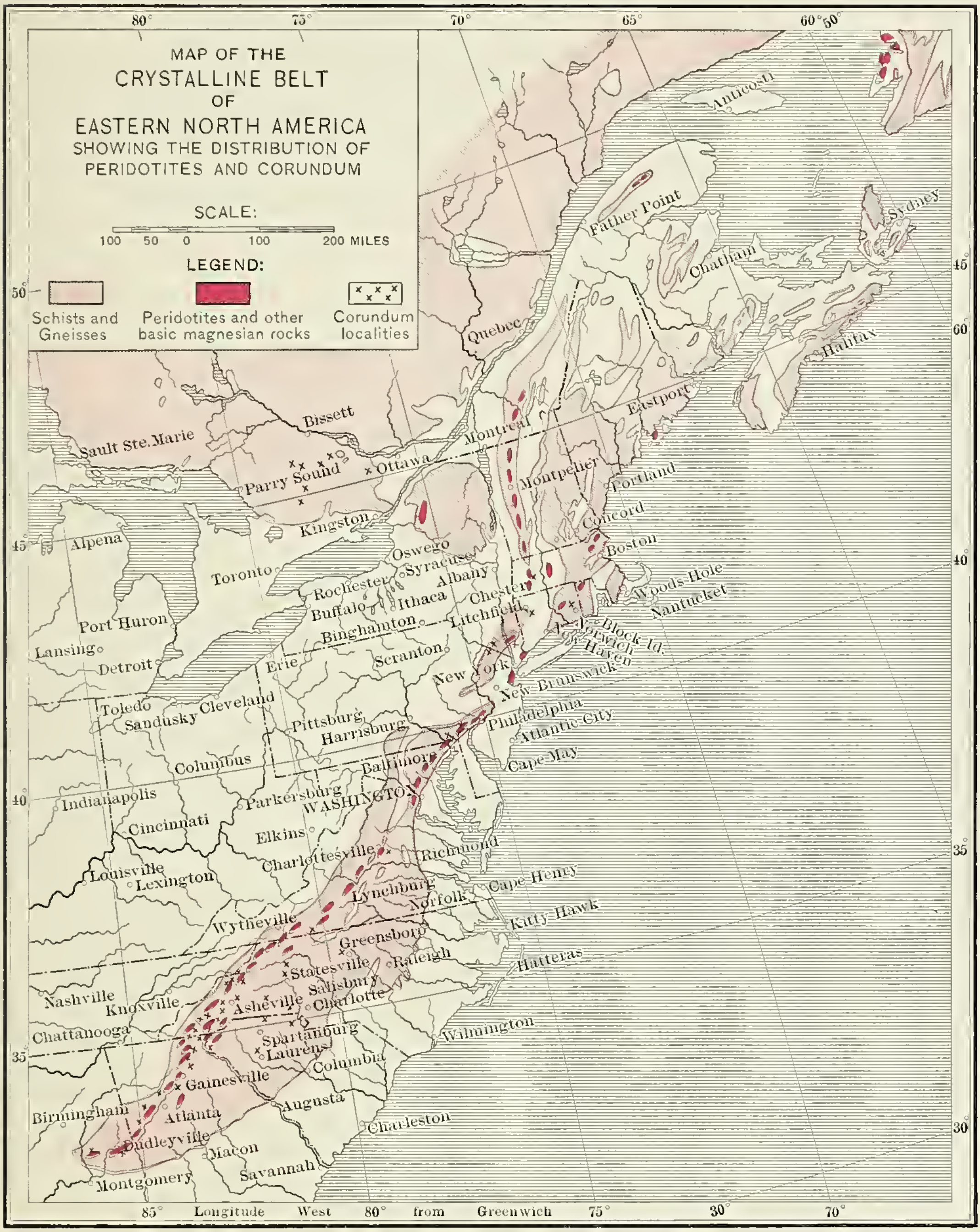
[5] The name "peridosteatite," it is believed, was first used by Henry Carvill Lewis, although he does not appear to have recorded it in any of his published writings. He applied the term to a talc-olivine rock that forms a series of outcrops from Chestnut Hill to Bryn Mawr, Pennsylvania. The groundmass of the rock is talc, massive or schistose, and irregular nodules and crystals of olivine, partially altered to serpentine, are scattered through it. Some of the olivines are twinned in such a way as to closely resemble staurolite crosses, and were formerly regarded as pseudomorphs of serpentine after staurolite.

[6] In view of the fact that chlorite rock of a massive character not infrequently occurs, it is proposed that it be named *chloritite*, in conformity with the well-established terms, peridotite and pyroxenite.



MAP OF EASTERN NORTH AMERICA, SHOWING THE DISTRIBUTION OF PERIDOTITES AND OTHER BASIC MAGNESIAN ROCKS.

Connecticut, Rhode Island, and Massachusetts, and again form a more continuous line through the crystalline belt of central Vermont and its continuation through southeastern Quebec, approximately parallel to the St. Lawrence River, into the Gaspé Peninsula. Large areas of serpentine are also known in western Newfoundland, and as these are doubtless a part of the same series, the belt of outcrops is extended to a length of over 2,000 miles.

In Alabama, Georgia, and North Carolina the peridotites are only partially altered, and serpentine is the exception rather than the rule. Through Virginia, Maryland, and Pennsylvania, however, the belt is represented chiefly by the secondary products, serpentine and soapstone. Yet, in discussing the origin of the Maryland serpentines, Dr. George H. Williams[7] states that "in many of these exposures the gradual transition to the little-altered olivine rock may be traced, both macroscopically and microscopically with great clearness."

Chromite is a constant accompaniment throughout the region, as an accessory constituent of the peridotites and their alteration products, and sometimes occurs in extensive segregated masses, or "pockets," constituting an important ore. In Pennsylvania, North Carolina, Georgia, and Alabama, corundum is also frequently associated with these rocks.

PERIDOTITES IN WESTERN NORTH CAROLINA.

Most of the peridotites and related magnesian rocks in western North Carolina are confined to the belt of gneisses and schists that lies chiefly west of the Blue Ridge, and are arranged generally in a somewhat well-defined belt or belts within these gneisses. In the southwestern counties, however, the outcrops are scattered over a region nearly 40 miles wide. The areas at Buck Creek, in Clay County, and Webster, in Jackson County, cover one-half and three-fourths of a square mile, respectively, and are the largest continuous outcrops of these rocks in the State.

Along the southern boundary of the State the peridotites are grouped roughly into three belts, located approximately in the valleys of the Hiwassee, the Little Tennessee, and the Chattooga rivers. Toward the north, however, these belts soon lose their individuality, and northeast of Corundum Hill the outcrops are pretty evenly distributed over the entire region. North of Waynesville the peridotites are found only in a single narrow belt, which crosses the French Broad River about 8 miles below Asheville, and extends northeastward by Burnsville, Bakersville, Cranberry, Boone, Jefferson and Sparta, crossing the North Carolina-Virginia boundary from the northeastern corner of Alleghany County, N. C., into the southeastern corner of Grayson County, Va. In the vicinity of Burnsville the outcrops are somewhat more scattering and the belt is wider than elsewhere north of the French Broad River.

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[7] Bulletin U. S. Geol. Survey, No. 28, 1886, p. 57.

The accompanying map of western North Carolina (Pl. II) shows the distribution of the peridotites and related rocks with as much detail as is practicable. It should be borne in mind, however, that a great majority of the outcrops are either narrow strips or small oval and lenticular masses, rarely exceeding 300 or 400 feet in width, and frequently much narrower. In most cases, therefore, it has been necessary to exaggerate these dimensions on the map for the sake of distinctness. Only a few of the largest outcrops, such as those at Webster and Buck Creek, could be represented true to scale.

Following is a somewhat detailed description of the distribution of these rocks, by counties, beginning with Clay County in the extreme southwest. More detailed petrographic descriptions of the principal occurrences are given in Chapter III.

PERIDOTITES IN CLAY COUNTY.

Peridotites are found only in the eastern portion of Clay County, on the waters of Shooting Creek, a tributary of Hiwassee River, and of Buck Creek, a tributary of the Nantahala.

Lying chiefly south of Shooting Creek, 3 miles above its mouth, are two lenticular masses of dunite, including irregular areas of troctolite and often accompanied by dikes of amphibolite (see fig. 1). The larger mass has a maximum width of one-fourth of a mile, and the narrow northern extension of it lies north of the creek, ending at the Behr corundum mine, near Elf post-office. Near W. C. Ledford's the outcrops over a large area are typical troctolite, weathering with the peculiar knotty appearance due to the greater resistance of the feldspars with their enclosing sheaths. A light-colored coarse-grained diorite, about 15 feet thick, was encountered near the northwest side of the peridotite in a tunnel across the gneiss-peridotite contact. Very near Elf, to the west, a narrow dike of grass-green amphibolite, bearing pink corundum, outcrops in the dunite near its eastern boundary. It extends southwestward through varying feldspathic facies, a distance of one-half mile, cutting the gneisses the greater part of this distance; and is probably continuous with a similar amphibolite in the peridotite south of the creek. Amphibolite with diorite and gabbro-diorite facies skirts along the western boundary also, as shown on the map. At the western border of the dunite, on the road at Elf, the outcrop shows interlamination of gneiss and dunite as follows: (1) gneiss west of the dunite; (2) dunite 2 feet thick; (3) gneiss 4 feet thick; (4) dunite, main mass. The lamination of the gneiss strikes N. 50° E. and dips northwest at an angle of 50°.

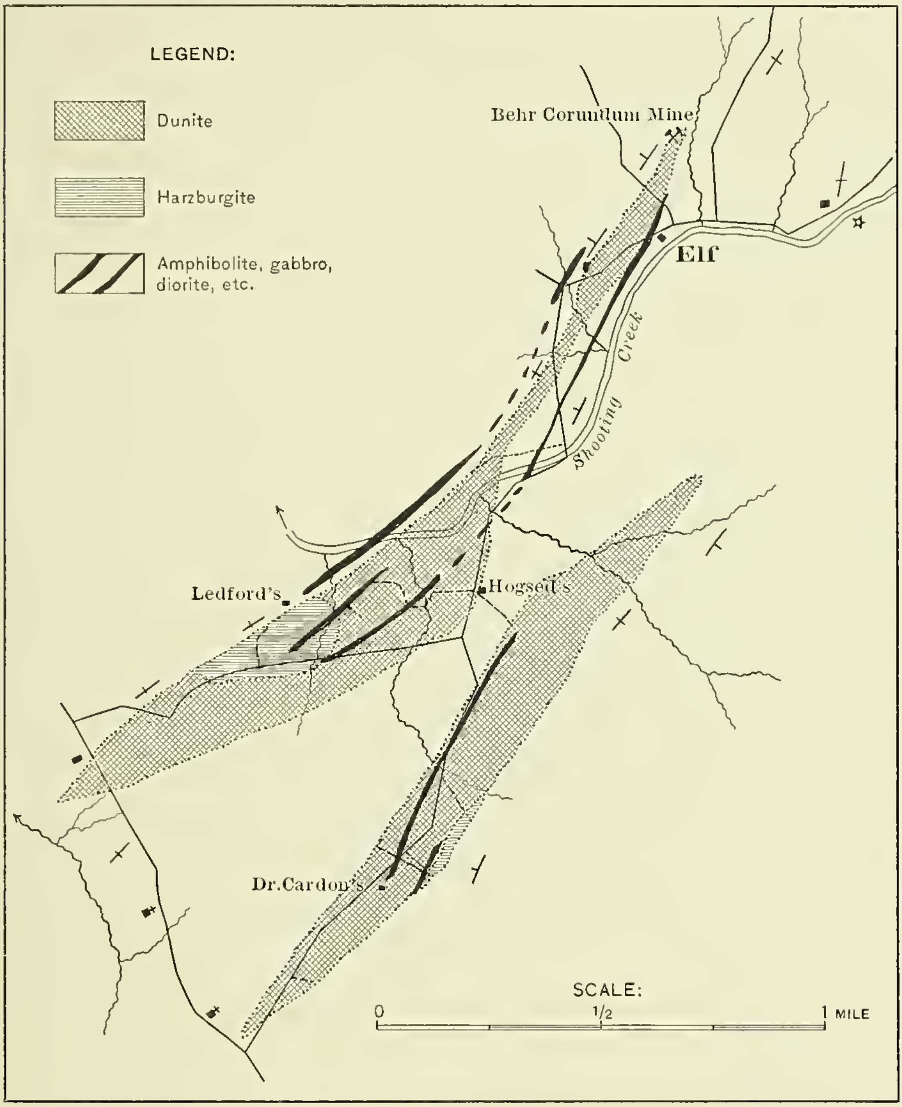


Fig. 1.—Map of peridotite areas near Elf, Clay County, N. C.

Outcrops of talc-schist at intervals for one and one-half miles northward, to the headwaters of Lick Log Branch, lie in direct line with the axis of this dunite area, and probably represent a continuation of it.

The smaller mass, as shown on the accompanying map (fig. 1), lies just southeast of the larger one, and at one point is only about 400 feet distant from it. It is approximately one and one-half miles long and has a maximum width of about one-eighth mile. Near the middle of its eastern border, and also near its western boundary, the dunite is accompanied by considerable amphibolite. Troctolite also occurs on the east, in part interlaminated with the dunite.

Corundum occurs in various associations throughout almost the whole extent of these peridotite areas, having been found in numerous mining and prospecting operations in the region shown on the map forming fig. 1.

Five miles east of Elf and one-half mile beyond Shooting Creek post-office, a narrow strip of dunite outcrops in several places in a line about 1½ miles long, extending southward across Giesky Creek. Corundum crystals, weathered out, are found in the fields. This line of outcrops is continued disconnectedly in a southwest direction across the Shooting Creek Mountains and down Bell Creek to within 1½ miles of Hiwassee, Georgia.

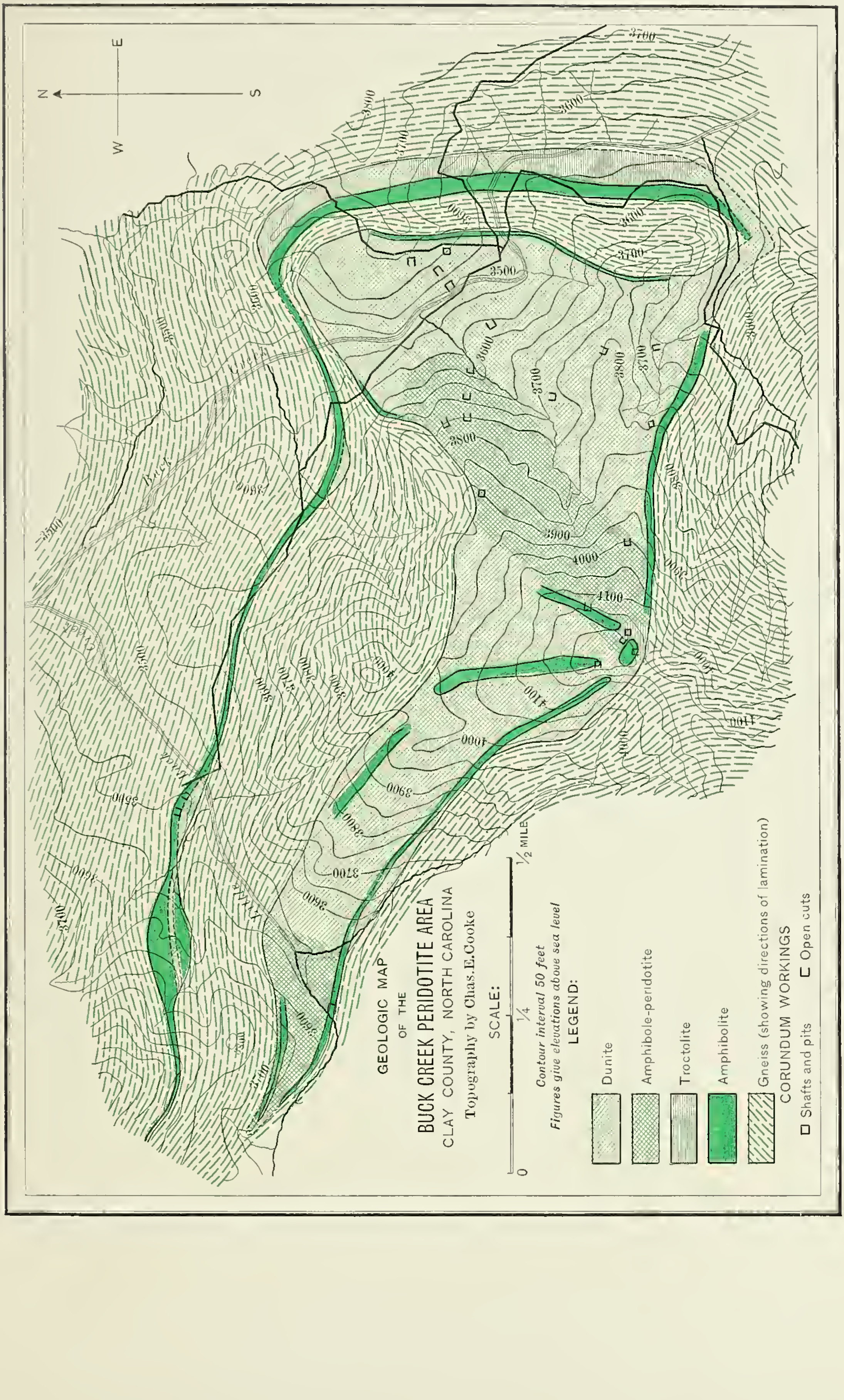
Two miles northeast dunite again appears in the same line, at the foot of Chunky Gal Mountain, associated with considerable talc-schist, amphibolite, and troctolite. Dunite outcrops occur at intervals for a distance of 3 miles across the mountain, extending to within a mile of the great area on Buck Creek, and bearing more or less corundum throughout. On both the east and west slopes of Chunky Gal Mountain the peridotites are frequently accompanied by a few feet of anorthosite along the borders next to the gneiss. This sometimes passes into dioritic facies and amphibolite, and often bears small amounts of corundum.

On Thumping Creek, 1 mile from its mouth, and 3 miles east of Shooting Creek post-office, two dikes of dark-green, fine-grained hypersthenite occur, about 500 feet apart, accompanied by corundum.

The largest compact area of peridotites found in the State is on Buck Creek (Pl. V). The area at Webster, Jackson County (Pl. VIII), is larger, but is greatly extended. The principal rock of the Buck Creek area is dunite, though large masses of amphibole-peridotite occur, smaller masses of troctolite, and many long, narrow dikes of amphibolite. The distribution of these rocks and their relation to one another and the inclosing gneisses are shown in some detail on the map (Pl. V). The area of the peridotite outcrop is approximately one-half a square mile.

PERIDOTITES IN MACON COUNTY.

With the exception of two or three small masses, the peridotites of Macon County, so far as observed, occur in a belt about 5 miles wide that crosses the county in a northeasterly direction about 5 miles southeast



MAP OF THE BUCK CREEK PERIDOTITE AREA, CLAY COUNTY, N. C.

of Franklin. The masses excepted are: (1) An area 1¼ miles northwest of Franklin, where fresh dunite was encountered in digging a well at William Blaine's, an extension of the rock for about one-fourth mile westward being indicated by soapstone outcrops, which are undoubtedly derived from it; (2) an area 12 miles southeast of Franklin, just south of the summit of Mount Scaly, at an elevation of over 4,000 feet, where corundum is found with schistose and fibrous radiating talc and the ocherous decomposition products of dunite. The decomposed materials accompanying the emery deposits of Dobson and Fairview mountains, 6 miles southwest of Franklin, are thought to be probably peridotites.

All other occurrences noted in the county have been found on the upper waters of Little Tennessee River, and on Ellijay and Walnut creeks, tributaries of Cullasagee River, which unites with the Little Tennessee at Franklin.

Just south of the State line, in Rabun County, Georgia, several peridotite outcrops were observed. One mile south of the line and 2 miles west of the river are two blunt, lens-shaped masses, one of dunite, measuring about 1,000 feet by 250 feet, and another near by consisting chiefly of enstatolite (enstatite rock) about 50 feet by 125 feet. The latter is largely altered to soapstone, and prospecting has disclosed the presence of corundum in the bordering chlorites. Another dunite mass was observed in the road a few rods south of the State line. The outcrop is distinctly wedge-shaped, being 30 feet wide on the east side of the road and only 15 feet on the west side. It is bordered by 6 to 10 inches of fibrous radiating talc and, outside of this, by a few inches of schistose chlorite and vermiculite, all inclosed within the lamination of the mica-schist of the country.

Within the next 9 miles north of the State line, down the river, twelve outcrops were located. Three-fourths mile west of the road, and the same distance north of the State line, up Commissioner Creek, dunite containing needles of colorless amphibole and octahedrons of chromite forms vertical cliffs about 100 feet high. On Mulberry Creek, one-fourth mile west of the road and 1¾ miles north of the State line, are two outcrops of soapstone, supposed to represent altered peridotite or pyroxenite. One-half mile further north and less than one-fourth mile west of the road, is an outcrop of dunite about 50 by 300 feet. The surface exposure is largely altered to talc, and fragments of the same material are reported to be found over the surface for more than one-fourth mile north and south of this place. One and a half miles northeast of this and one-half mile west of the road is a lenticular mass of dunite in every way similar to the last, with dimensions of about 40 by 150 feet, the longer axis lying N. 20° E. Very little normal dunite is seen at the surface, the outcrops being chiefly talc. This locality is about 1 mile southwest of Otto (Smith's bridge).

About one-half mile north of Otto, west of the river, an outcrop of dunite 50 to 60 feet wide occurs in the road, just opposite the mouth of Tessentee Creek. It is enclosed in the lamination of biotite-gneiss and crumpled mica-schist, which strike N. 40° E. and dip northwest at an angle of 60°. Just south of Tessentee Creek and one-half mile north of Otto is a dunite outcrop about 100 feet wide; and one-half mile east of this, up the creek, is a soapstone outcrop that probably represents an altered peridotite or pyroxenite. Three and one-half miles northwest of Otto, on the North Fork of Coweta Creek, is another outcrop of soapstone associated with chlorite. One mile northeast of this, across the mountain spur, on the headwaters of Skenah Creek, similar outcrops of talc and chlorite are found, and scattered fragments are said to occur over the surface of the intervening region. One mile east of this, on the mountain spur, is the south end of a peridotite outcrop that extends N. 40° E., for a distance of 2 miles, to the road near the mouth of Skenah Creek. It has a maximum width of about 500 feet, and the outcrops are chiefly talc with more or less chlorite, ledges of dunite occurring only near the middle.

Near the middle of the peridotite area last described, in the road at R. W. Bates', is an exposure in which the contact between the gneiss and the peridotite is distinctly seen. It is remarkable from the fact that the lamination developed here in the dunite makes an angle of 20° to 25° with that of the inclosing gneiss. The dunite strikes N. 55°-60° E., the gneiss N. 80° E. This locality is 6 miles south of Franklin.

About half a mile east of the river, just opposite the mouth of Skenah Creek, outcrops and numerous scattering fragments of talc and chlorite probably represent altered peridotite or pyroxenite. Two and a half miles east of the river, near the summit of the western spur of Fish Hawk Mountain, at the head of Hickory Knoll Creek, a mass of dunite about 100 feet wide occurs in gneisses whose lamination strikes about N. 20° E. and stands vertically. Rounded blocks of the dunite are inclosed in radiating talc (Pl. XIV, A). Sometimes only a small mass of dunite remains in the middle, and in some nodules the radiating mineral extends entirely to the center, the nodules containing no dunite whatever. The surface of the dunite has weatherd to a red, clay-like material, and similar ocherous material has replaced the dunite of many of the talc-encased boulders. Corundum has also been found here in small quantities.

A spur of the Cowee Mountains 6 miles long, running southwest from Cedar Cliff Mountain to Cullasagee River at Corundum Hill, and lying between Ellijay and Walnut creeks, is thickly dotted over with small areas of peridotite and pyroxenite, chiefly dunite. On this spur, which comprises an area of less than 15 square miles, about 25 independent masses were seen. At most of them corundum has been found and more or less prospecting or mining has been done. The lens-shaped masses of this region vary from 20 to 500 feet in width of outcrop, and from less than 100 feet to nearly a mile in length. Usually the length is not more than four or five times the breadth. The longer axes conform in a general way to the trend of the lamination in the gneisses, which in this region is usually N. 25°-50° E. The Corundum Hill peridotite (Pl. VI) is an irregular, lens-shaped mass about 400 by 1,200 feet in its greatest dimensions. It differs, however, from the majority of such masses in being much more blunt at the ends, and in its finger-like apophyses that branch off from the western border. Similar characteristics are found in a few other places, as in the Hamlin mine, at the head of Ellijay Creek, 11 miles from Franklin (see fig. 2).

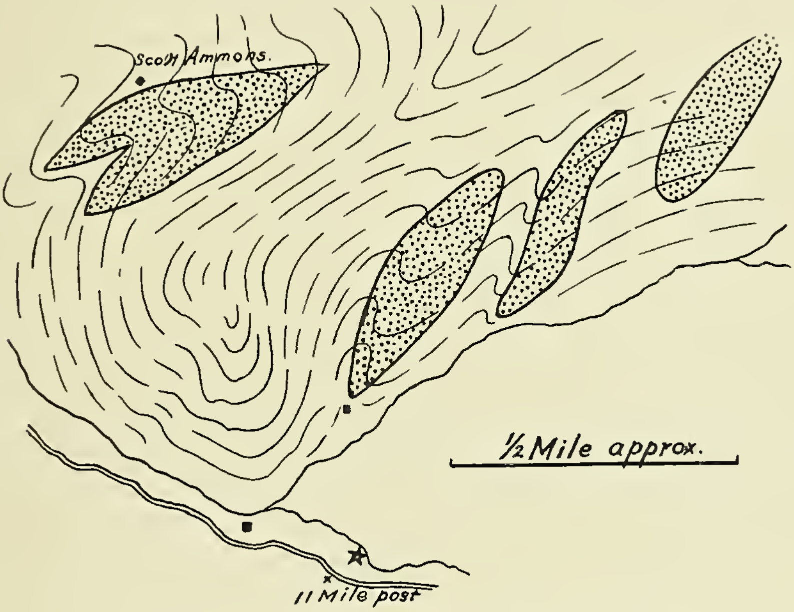


FIG. 2.—Sketch map of peridotite outcrops of the Hamlin mine.

Enstatolite (enstatite rock), which frequently occurs with the dunite in varying proportions, forming generally but a small part of the mass, is sometimes predominant, and, in a few places, as at the Littlefield mine, constitutes the whole mass of the rock. It is often largely altered on the surface, and especially along the borders, into talc.

The whole area between Walnut and Ellijay creeks has been vigorously prospected, and corundum has been found at almost every outcrop of peridotite and pyroxenite. At two or three places active mining has been done and considerable corundum has been produced. This mineral has also been found on the eastern slope of Onion Mountain, north of Ellijay Creek, with soapstone, which doubtless represents an altered peridotite or pyroxenite. Similar soapstone outcrops are found in places on the south slopes of the mountain, near Ellijay Creek.

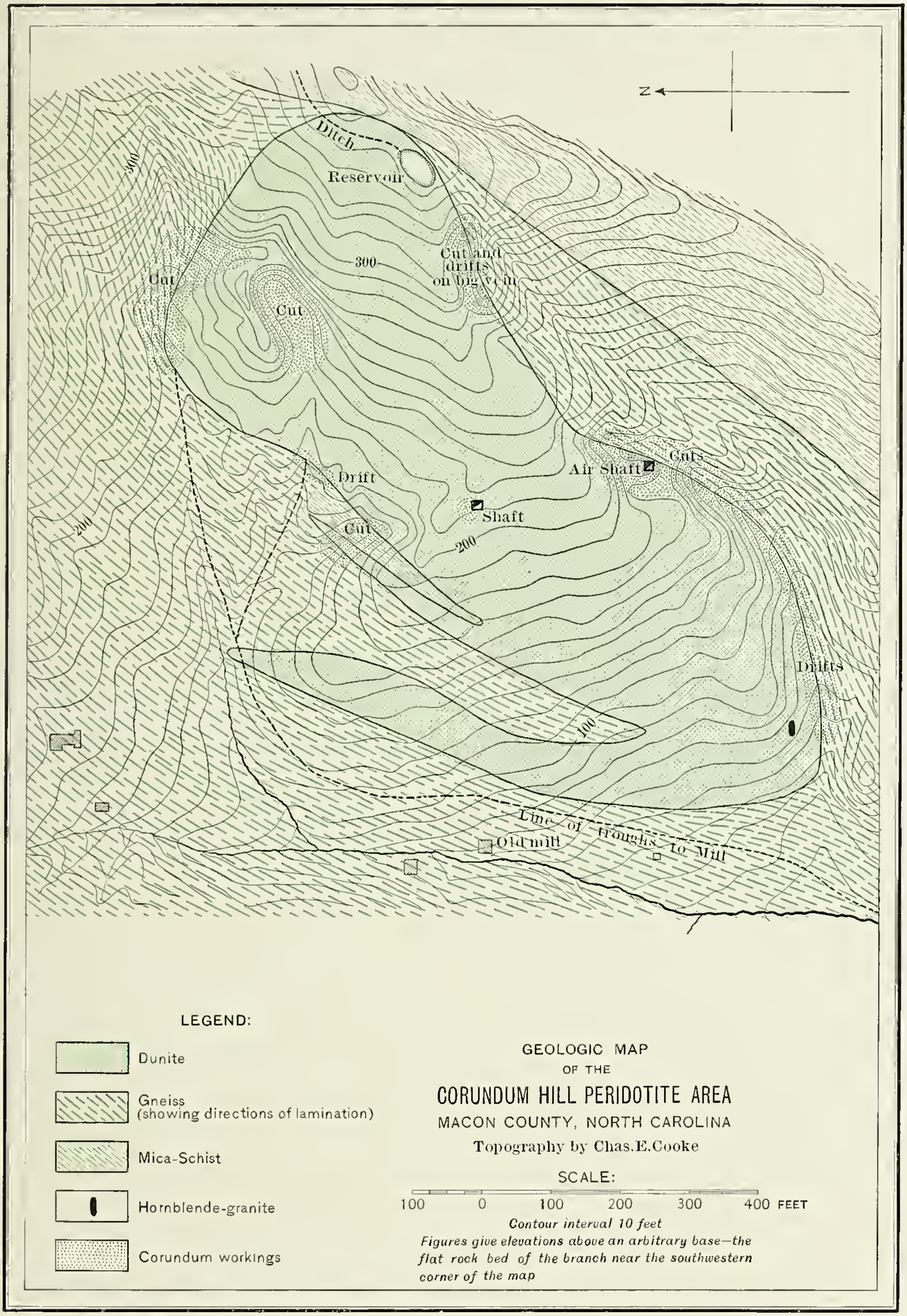
PERIDOTITES IN JACKSON COUNTY.

The peridotites of Jackson County are found chiefly in the vicinity of Sapphire in the southeast, and about Webster and northwestward toward Balsam Gap, where the railroad crosses toward Waynesville. Several small, scattered outcrops are also found about the headwaters of the West Fork of Tuckaseegee River, in the vicinity of Glenville.

At the Whitewater mine, on the Whitewater River, 5 miles southwest of Sapphire and 3 miles north of the State line, is an oval outcrop of peridotite about 100 feet in width, with some pyroxenite (enstatolite). The peridotite is chiefly harzburgite (olivine-enstatite rock). Corundum occurs in fine, scaly vermiculites along the joints and in the contacts with the gneiss. Soapstone, which probably represents similar rocks, occurs on the southern slopes of Terrapin Mountain, 2 miles west of the Whitewater mine. A small mass of peridotite is said to occur on the north end of Whiteside Mountain, near Devils Courthouse.

The accompanying map (Pl. VII) shows the distribution of peridotites about Sapphire, which, in nearly every case, contain more or less corundum. The most southerly outcrop, 1 mile south of Sapphire, is at the Bad Creek mine, where a lenticular mass about 50 by 200 feet consists chiefly of enstatolite (enstatite rock), but, by the introduction of olivine, passes in places into harzburgite and dunite. The corundum found here is associated with a remarkable variety of minerals, described on p. 254.

One-half mile northeast of this is the Socrates mine, where a great lens of enstatolite occurs, about 250 by 900 feet. The contact with the gneiss was distinctly observed here at two points. At the northeast end of the outcrop the gneiss dips about southeast under the pyroxenite at an angle of 40°. One or two feet of the gneiss at the contact are thickly impregnated with fine, scaly vermiculite. Between this and the pyroxenite is a sheet of similar vermiculite about 4 inches thick, and next to


N
300
Ditch
Reservoir
300
Cut and drifts on big vein
Cut
Cut
Air Shaft
Cuts
Drift
Shaft
Cut
200
200
100
Drifts
Line of troughs to Mill
Old mill
LEGEND:
Dunite
Gneiss (showing directions of lamination)
Mica-Schist
Hornblende-granite
Corundum workings
GEOLOGIC MAP
OF THE
CORUNDUM HILL PERIDOTITE AREA
MACON COUNTY, NORTH CAROLINA
Topography by Chas.E.Cooke
SCALE:
100 0 100 200 300 400 FEET
Contour interval 10 feet
Figures give elevations above an arbitrary base—the flat rock bed of the branch near the southwestern corner of the map

MAP OF THE CORUNDUM HILL PERIDOTITE AREA, MACON COUNTY, N. C.

the pyroxenite a few inches of pulverulent and scaly talc, with a little chlorite. The pyroxenite itself is partly altered to talc on the outside. Near the middle of the northwestern border an open cut in the gneiss extends 100 feet from the contact, exposing the section shown in fig. 3. It will be observed that the lamination of the gneiss is scarcely disturbed, except that it is steeper as the pyroxenite is approached. The contact plane is somewhat irregular but nearly vertical, and the gneiss is noticeably more decomposed within 10 feet of it.

One-fourth mile north of Sapphire is a lenticular mass of chloritic amphibolite, measuring about 20 to 75 feet, which should probably be considered as related to the pyroxenites and peridotites.

One-half mile northeast of Sapphire is a large forked mass, with dimensions approximately 500 by 1,000 feet, consisting chiefly of grayish dunite, but passing into large masses of enstatolite (enstatite rock) at the southeastern point. Chrysotile has been developed in this portion, giving the name "Asbestus mine" to this place. Corundum is also found here.

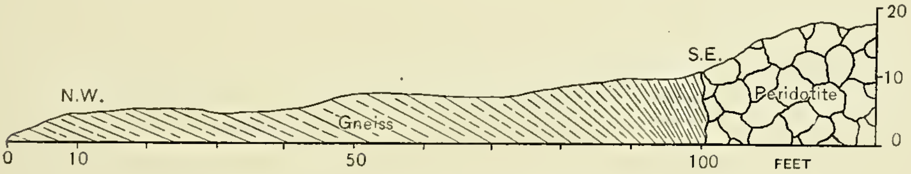


Fig. 3.—Vertical cross-section of contact of peridotite and gneiss at Socrates mine, Sapphire, Jackson County, N. C.

One-fourth mile east of the Asbestus mine is the Sapphire mine, where dunite and enstatolite (enstatite rock) together form a mass about 100 feet wide and 900 feet long, lying east and west. The dunite bears considerable colorless amphibole in long slender needles.

One and a half miles northeast of Sapphire is a lens-shaped mass of harzburgite about 150 by 400 feet in outcrop, with its longer axis north and south. The openings made here for corundum are known as the Rattlesnake mine. The rock is remarkably coarse in texture, consisting of large radiating blades and tufts of enstatite with grains of olivine often 2 or 3 inches in diameter and frequently with well-developed cleavage. On exposed surfaces, where the enstatite has altered to talc and the olivine more or less weathered out and altered to serpentine, the rock is strikingly like the peridosteatite in the vicinity of Bryn Mawr, Pennsylvania. This rock at the Rattlesnake mine has a slightly laminated structure. At the south end of the mass the gneiss dips north about 25°, passing under the peridotite.

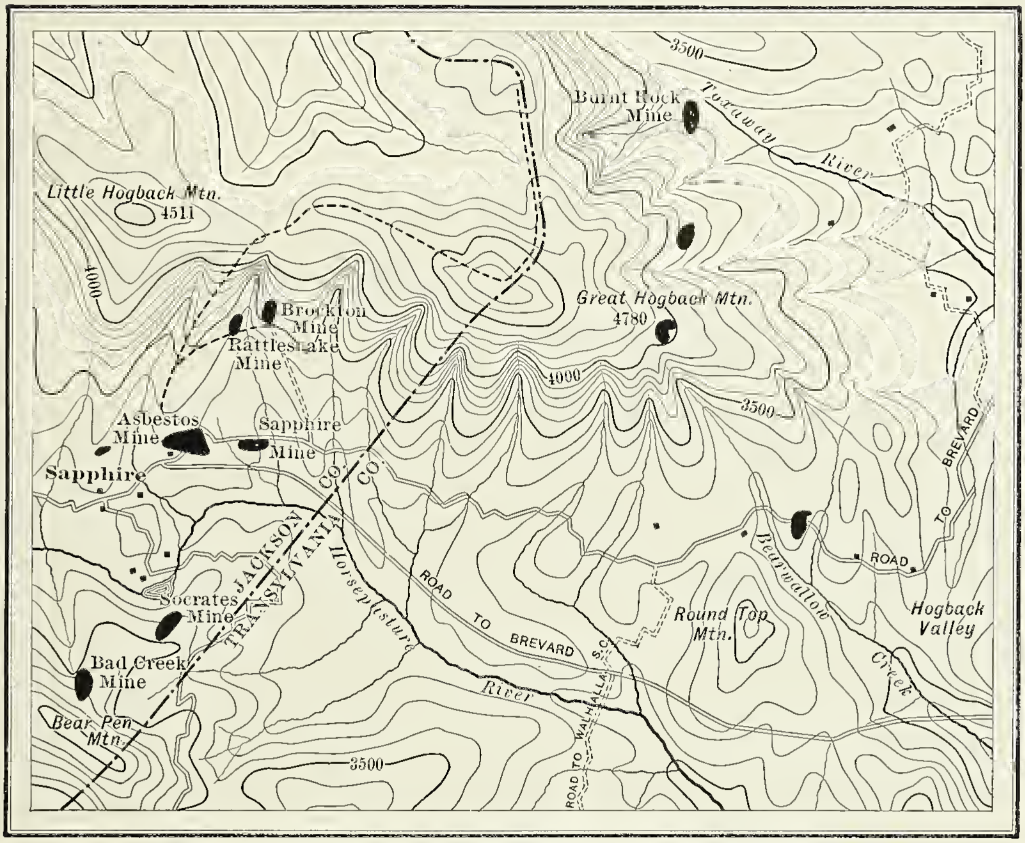
Just across the deep ravine one-fourth mile from the Rattlesnake is the Brockton mine, where a mass of fibrous and tufted enstatolite (enstatite rock) occurs in an outcrop about 200 by 400 feet. A slight lamination is developed in the direction of the longer axis, N. 70° E.

The six places here designated as "mines" (Bad Creek, Socrates, Asbestus, Sapphire, Rattlesnake, and Brockton) were all worked more or less by the Sapphire Corundum Company (now the Toxaway Company) for corundum, as were also the Whitewater mine, described above, and the Burnt Rock, in Transylvania County.

Five miles northwest of Sapphire and one-half mile north of the summit of Sheep Cliff Mountain, large outcrops of dunite occur. A mile north of this and one-fourth mile north of Double Knob Mountain, asbestos was found in a shallow prospect pit.

Within 4 miles northeast and southwest of Glenville, twelve similar lenticular masses of enstatolite, with smaller proportions of harzburgite and dunite, were located. A small amount of prospecting has disclosed the presence of corundum at a number of these places. The outcrops closely resemble in all their characters the similar masses in the vicinity of Sapphire. Three miles north of Glenville, on the east slopes of Shoal Mountain, near the north end, are found numerous very large boulders of amphibole-peridotite, very much altered at the surface to chlorite. Schistose talc and chlorite occur in a number of places on the East Fork and Caney Fork of Tuckaseegee River, and on Cullowhee Creek. It is quite probable that some of these outcrops are the alteration products of peridotites or related rocks. Near the head of East Fork dunite and enstatolite (enstatite rock) occur in several places on Wolf Mountain, near the mouth of Tessentee Creek.

The largest peridotite area in the State, and in many respects the most remarkable one in the Appalachian region, occurs at Webster (Pl. VIII). The area of exposure of these rocks approximates three-fourths of a square mile, but it lacks the compactness of the Buck Creek area, which is next in size, and the usual lenticular form is almost entirely lacking. The line of outcrops traces an almost unbroken ellipse, passing through Webster at the southwestern and near Addie at the northeastern extremity of the major axis. This axis is 6 miles long and lies about N. 25° E. The minor axis is about 3½ miles long. The width of outcrop varies from more than 1,600 feet at Webster to thin belts of schistose talc, 10 feet or less at several places. On the eastern side of the ellipse, along Cane Creek, the continuity of the outcrop is broken in five places within a distance of a little more than a mile. The four disconnected masses have the usual lenticular form.



MAP OF THE PERIDOTITE AREAS NEAR SAPPHIRE, JACKSON COUNTY, N.C.

SCALE

1 ½ 0 1 2 MILES

Lateral projections of various forms extend from the main body of the peridotite into the surrounding gneiss in five places. Also, 1 mile northwest of Addie, a lens-shaped area of gneiss, about 450 by 1,300 feet, is entirely surrounded by peridotite. Throughout the Appalachian region these rocks frequently exhibit more or less lamination, but this character is seldom so highly developed as in the vicinity of Webster. It is particularly well shown in the large barren outcrop at the Tuckaseegee River (Pl. IX, A). The lamination is so minutely developed that it is clearly seen in the hand specimen (Pl. IX, B). So far as observed, the lamination in this vicinity conforms to that of the gneiss. The gneiss dips toward the southeast and northwest, away from the major axis of the peridotite ellipse, and, in general, the dip is steeper farther away from this axis, indicating an anticlinal structure in the form of an inverted boat.

At the western border of the large outcrop at the Tuckaseegee River two shallow cuts show an interlamination of the dunite with the gneiss, like that observed near Elf, in Clay County. The cuts show the following succession: (1) gneiss to the west; (2) laminated dunite 10 feet; (3) thinly laminated gneiss 6 feet; (4) dunite, western border of main mass. In the town of Webster, also an outcrop in the street just south of the court-house shows 12 feet of dunite, conformable to the lamination of the gneiss and near the western border of the principal dunite outcrop.

In the midst of the barren hillside by the river is also the type locality of websterite, the pyroxenite consisting essentially of orthorhombic and monoclinic pyroxenes, first described by Dr. George H. Williams.[8] This rock constitutes a mass about 550 feet wide, entirely enclosed in the dunite, and it may be traced by smaller outcrops north and south for a distance of about a mile. On the hillside facing the river, the dunite outcrop is 200 feet wide east of the websterite, and 700 feet wide west of it. Websterite is again found 3 miles east of Webster, on Cane Creek, 1 mile above its mouth. Only a small mass occurs here, on the western border of the dunite. These two are the only known localities where websterite is found in the State. By the failure of the monoclinic pyroxene, or by segregation of the orthorhombic, masses of the latter several feet in diameter sometimes occur within the websterite, giving examples of bronzitite on a small scale.

Two and one-half miles up Cane Creek, on the east bank, in the vicinity of the gaps in the peridotite belt, and one-fourth mile east of the main body of this rock, is an outcrop of fresh granular dunite only a few feet in extent. In half a dozen or more places in a direction

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[8] American Geologist, Vol. VI, 1891, p. 44.

N. 40° E. from this place, toward Balsam Gap, are found talc and more or less decomposed dunite for the distance of about a mile, ending at Soapstone Gap. Then, for 4 miles toward Balsam Gap, only crumpled and greatly contorted gneisses were observed.

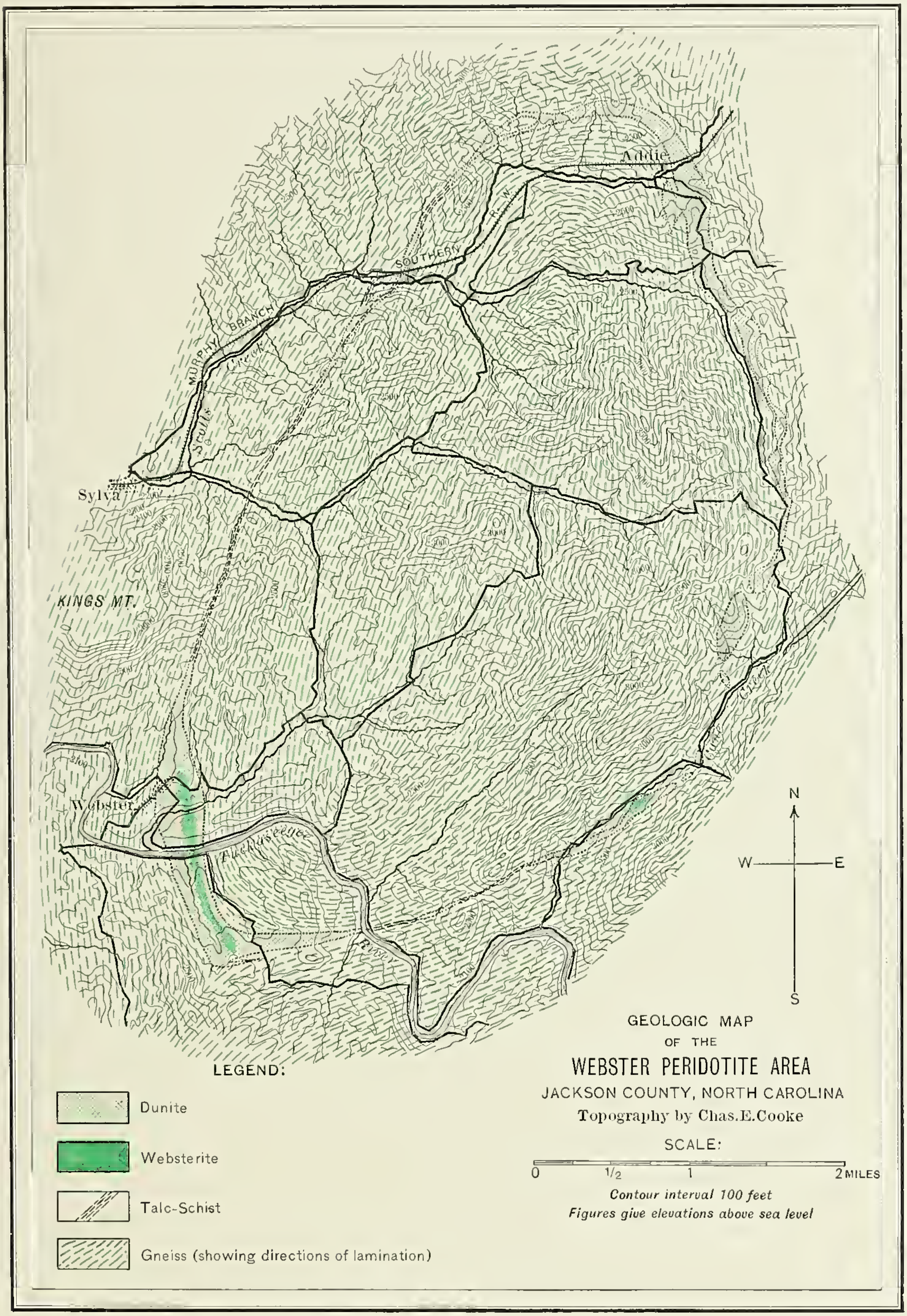
Two miles west of Balsam Gap is a great oval mass of peridotite, 800 by 1,200 feet in outcrop, occupying the point of a ridge between Dark Ridge Creek and Jones Creek, and cut by the railroad at Bryson's mill. The slopes are steep and the outcrop is made prominent by numerous ledges and cliffs, besides great numbers of loose boulders. The rock is chiefly harzburgite, passing in places into smaller masses of dunite and enstatolite. The harzburgite is unusually coarse grained, some of the great olivine anhedrons being five and six inches in diameter, though most of the grains are less than one-fourth of an inch. Numerous glistening bronzy plates of enstatite, often altered to talc, are scattered through the mass. Talc is almost universally developed in the joints of the rock; and, doubtless as a result of this, several landslides of small dimensions have occurred on the eastern face of the hill. A dunite dike 7 inches thick stands out prominently in the railroad cut in the midst of the harzburgite. The walls of this dike are sharply defined and a typical columnar structure is developed at right angles to them (Pl. X, A).

Half a mile north of Bryson's mill, on top of the ridge, there is a small outcrop of similar harzburgite, with talc abundantly developed. Half a mile due east of this a similar but larger mass forms the prominent point of a ridge (Pl. X, B) and extends down the slope to the southwest nearly half a mile. Two miles south of Balsam Gap, in Bee Tree Gap, is another small area of peridotite.

PERIDOTITES IN TRANSYLVANIA COUNTY.

The Whitewater mine of the Toxaway Company, described above, is located on the Jackson County side of the Whitewater River. Just across the river to the northeast, in Transylvania County, smaller outcrops of peridotite of a similar nature also occur. About a mile east of this and the same distance south of Buck Mountain, on the steep eastern slopes of the river gorge, are heavy cliffs of a coarse harzburgite in which enstatite and olivine occur in about equal amounts. The width of the outcrop in horizontal extent is about 100 feet. The place is known as the "Koons place," and some prospecting has been done here for corundum.

One mile east of Buck Mountain and 4 miles due south of Sapphire, a mass of dunite 150 feet wide outcrops in the road. It bears needles of colorless amphibole, and, in places, some enstatite. Chromite, in blocks weighing several pounds, also occurs weathered out over the surface.



MAP OF THE WEBSTER PERIDOTITE AREA, JACKSON COUNTY, N. C.

This mass continues northward three-fourths of a mile to Dr. C. Grimshawe's "Gem mine," where transparent, red, blue, and colorless fragments of corundum have been found in prospecting. Similar fragments occur on the surface for about a mile still farther northward. South 20° west from the outcrop in the road the peridotite outcrops prominently for more than a mile, with many large surface boulders.

About a mile northeast of the "Gem mine," and one-fourth mile below the falls of Thompson River, there are many large soapstone boulders, which probably represent pyroxenite. One mile east of this, peridotite occurs on the road crossing the mountain by Rocky Knob.

Three or four miles east of Sapphire several dunite outcrops occur southeast of Great Hogback Mountain, one of them showing in the road at Hogback Valley post-office. Other occurrences are found on the northeastern slope of Great Hogback, one of these being the location of the Burnt Rock mine of the Toxaway Company. At the latter place are heavy outcrops of enstatolite (enstatite rock) and harzburgite, chiefly the former, of coarse-bladed texture. Corundum occurs here in massive blocks with large quantities of chlorite. Two miles north of Burnt Rock mine is another outcrop on Panthertail Mountain.

In a distance of about 15 miles northeast of Great Hogback Mountain about a dozen small outcrops of harzburgite and enstatolite were observed on the waters of the North Fork and West Fork of French Broad River. A number of these are composed entirely of enstatolite, and the numerous small soapstone masses throughout this region were doubtless derived from the same or a similar rock. Thin bands of talc- and chlorite-schist extend also through this region and northeastward into the Pink Beds, in the extreme northern corner of the county. A little prospecting has been done and corundum has been found at a few of these localities.

Near Brevard, a mass of dark green serpentine is exposed in a cut of the Transylvania Railroad.

PERIDOTITES IN SWAIN COUNTY.

About 3 miles a little southwest from Bryson, on the farm of D. W. Kerr, there is an outcrop of peridotite covering 20 acres or more. Its greatest dimension is nearly three-eighths of a mile and lies north and south, while its maximum width is not over 400 feet. The rock is composed largely of olivine with a little enstatite. It is covered in many places by soil, but on the slopes of the hill there are bare outcrops. Corundum is said to have been found with this peridotite, but the prospecting that has been done gives no indication that this mineral occurs in commercial quantity.

No other outcrops of these rocks have yet been found in this county.

PERIDOTITES IN HAYWOOD COUNTY.

Northeast of the peridotites of Balsam Gap, Jackson County, no rocks of this character have been observed for a distance of about 15 miles. North of that part of Pigeon River between Clyde and Canton, a number of scattered outcrops of soapstone occur on the spurs of the Newfound Mountains. One of these is crossed by the road in the gap between Chambers and Glade mountains, 5 miles northeast of Clyde, where the exposure of soapstone has the typical structure and appearance of enstatolite. Corundum is said to have been found at this place.

Two and a half miles northeast of Canton, dunite occurs on the North Fork of Hominy Creek. The outcrop has a width of several hundred feet near Hominy Grove church, and extends northward in a narrower strip for about one-half mile. Some well-formed corundum crystals have been found here. On the head of North Fork, one-half mile south of Newfound Gap, a lenticular dunite mass occurs with a surface exposure of about 40 by 100 feet. Red corundum occurs here, and a little prospecting shows conditions very similar to those at Corundum Hill, Macon County. Northeastward, toward the gap, a narrow strip of talc-schist occurs, and a small outcrop of dunite is found just north of the church in the gap. In line with this dunite small outcrops of talc occur one-half mile northeast of the gap. Lying only a few hundred feet east of this dunite in the gap, another dunite mass extends from the crest of the ridge one-fourth mile down the north slope, upon the headwaters of Newfound Creek, tapering to a point 200 yards below the road.

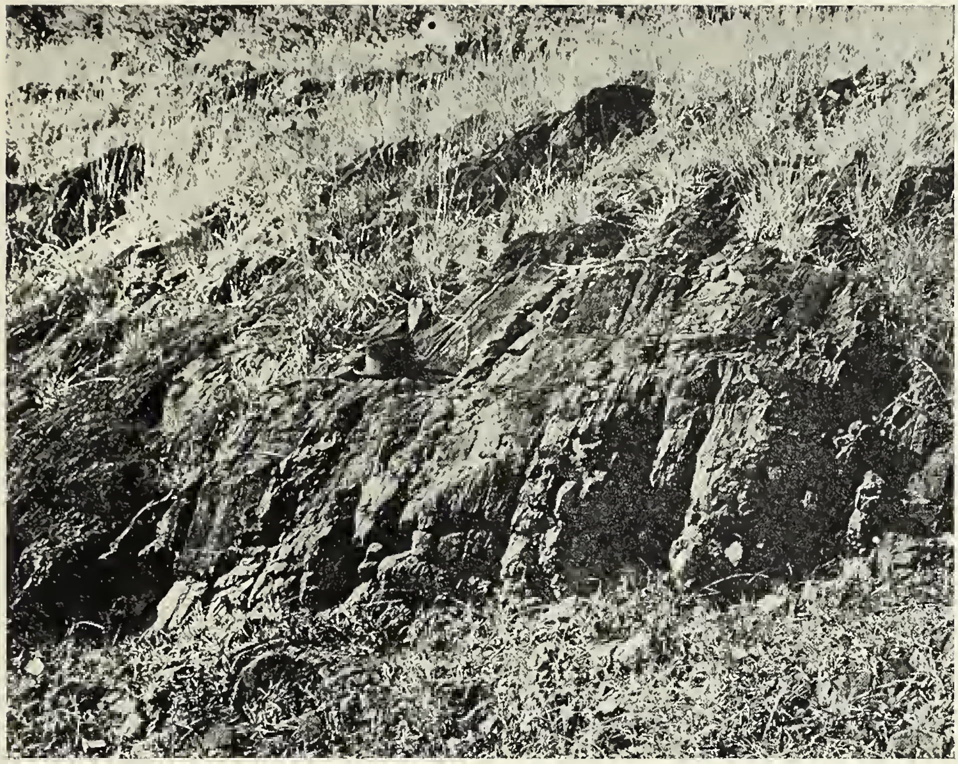
At the Presley mine, 4 miles northeast of Canton, there is a mass of dark green amphibolite intersected by pegmatite dikes carrying corundum.

PERIDOTITES IN BUNCOMBE COUNTY.

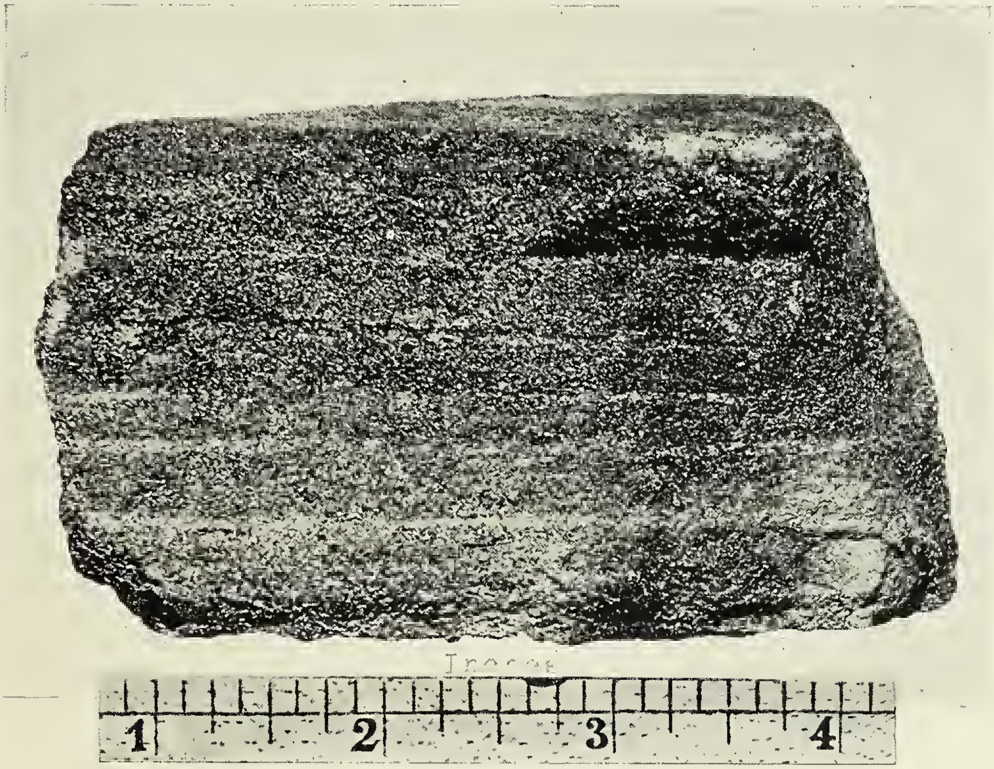
Two and a half miles northeast of Newfound Gap, down Newfound Creek, soapstone, apparently derived from pyroxenite, occurs on the mountain slopes west of the creek.

Eight miles northeast of Newfound Gap and one mile east of Leicester, dunite outcrops on the Asheville road just east of Newfound Creek. It is about 30 feet wide and forms the center of a small knoll upon which a house is built. From 2 to 2½ miles southeast of Leicester, on the road to Juno (Penland's mill), three outcrops of light-gray to greenish serpentine were observed in and near the road, varying in width from 10 to 40 feet. Half a mile southward a similar strip of serpentine is crossed by the Asheville road.

For 10 miles northeastward from this place, across the French Broad River and to the Flat Creek Mountains beyond Weaverville, the peridotites are represented almost entirely by outcrops of serpentine and soap-



A, OUTCROP OF LAMINATED DUNITE AT WEBSTER, JACKSON COUNTY, N. C.



B, HAND SPECIMEN OF LAMINATED DUNITE, FROM WEBSTER, JACKSON COUNTY, N. C.

stone. At one point, however, typical fresh dunite is closely associated with equally typical serpentine masses. This interesting occurrence is just east of Newfound Creek, near the road that crosses it 2½ miles east of Leicester. Here two outcrops occur side by side about 150 feet apart, one, composed of serpentine, 10 feet wide, and the other, of fresh dunite, about 30 feet wide. In shallow prospecting pits both of them show the presence of chromite grains and green nickel stains. The dunite is laminated and very similar in appearance to that at Webster, in Jackson County. From 200 to 300 feet down the hill, southwest of the serpentine mass, in the direction of the lamination of the gneiss, an outcrop of dunite 5 feet thick occurs in the branch. Between this dunite and the serpentine on top of the hill no outcrops of any kind could be found.

Light-gray to greenish-gray serpentine occurs also at the mouth of Dicks Creek, one mile further down Newfound, and similar rock is said to occur at the bridge one-half mile below. Continuing in the same direction, serpentine 100 feet wide and about one-fourth mile long occurs within one-fourth to one-half mile of French Broad River and three-fourths mile north of the mouth of Newfound Creek. The rock is mostly mottled light gray and sometimes contains numerous chromite grains. It forms a distinct ridge through the fields, and the soil is said to be better adapted to corn and tobacco than the clay soil of the adjoining gneiss.

Directly northeast of the last locality, on the south bank of the French Broad, 2 miles above Alexander, dark-green massive serpentine occurs in an outcrop 15 feet wide, associated with a little talc and chlorite and considerable chrysotile. On the opposite (north) bank of the river a narrow strip of serpentine shows in the road, narrowing toward the river into a thin strip of talc, which disappears altogether in a few feet.

One-half mile below the last named locality, and 1½ miles above Alexander, a broad belt of serpentine occurs north of the river. The outcrop is bordered by schistose talc and chlorite, and there is considerable development of a radial mineral along the borders and principal joints of the main mass of serpentine, similar to that in the dunite of Corundum Hill, Buck Creek, and other localities. At many of the serpentine localities throughout this region more or less of this structure was observed. In all cases, however, the radiating mineral has been altered to serpentine, whereas with the dunite it is usually changed to talc. One mile northeast of this locality, on Reems Creek three-fourths mile above its mouth, is a mass of yellowish-green to dark-green compact serpentine. Large nodules (2 feet in diameter) composed of small blade-like and fibrous gedrite in confused aggregates, occur in the midst of the serpentine.

These nodules are inclosed by radial sheaths of the same mineral, similar in appearance to those described above.

Between this point and Flat Creek Mountains, 4 miles northeastward, two prominent outcrops of serpentine were observed; one on the Weaverville-Alexander road, and the other one-half mile north of this road, but within a mile northwest of Weaverville. At the latter place the surface of the outcrop revealed only soapstone, but a shallow cut shows the mass of the rock to be serpentine, with talc developed along the irregular joint planes, thus forming a thick sheathing around the serpentine blocks. One and one-half to 2 miles north of Weaverville, talcose rocks are found in several places near the ford of Little Flat Creek. An outcrop near the ford consists largely of white to greenish talc-schist, but also contains compact masses of a confused fibrous structure. These masses are exactly similar in appearance to the gedrite masses in the serpentine on Reem Creek, and like them are surrounded by radial sheaths of coarser crystallization, all altered into talc.

Dunite occurs again northeast of this point, near Flat Creek, one-half mile above the ford. The outcrop is normal yellowish to greenish-gray olivine rock, with no massive serpentine. Some talc and chrysotile are developed, partly in the form of radial sheaths along the borders and joints. On Flat Creek, 2 miles above the road, talc occurs associated with chalcedony and the ocherous products of decomposed peridotite or serpentine. Incrustations of green nickel silicates are also abundant at this place.

Serpentine occurs again north of Flat Creek Mountains and 2 miles northeast of Stocksville in a small decomposed outcrop in the road. Half a mile east of this and 1½ miles southwest of Democrat, dunite occurs in a laminated and much contorted outcrop about 300 feet wide at the road. Large quantities of talc are present, much of it in the form of radial sheaths along the joint planes, and considerable dense brown chalcedony. Southwestward this outcrop quickly thins down into a narrow strip of talc-schist, which continues S. 30° W. into Flat Creek Mountains. The dunite gradually widens northeastward to a maximum of about 500 feet, and continues with great uniformity for a distance of 1⅓ miles N. 20° E. to Ivy River, where it rapidly narrows down to a point. The greater part of this outcrop is distinctly laminated like that at Webster. Chromite grains are abundant throughout the rock, and considerable masses are often encountered. Green nickel stains are also very prevalent in the joints.

In line with this outcrop, north of the river, narrow strips of talc occur 250 yards west of Democrat. Similar strips of talc and small lens-shaped masses of dunite occur at intervals in the same direction to

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the Madison County line, on top of the ridge north of Ivy River. Some of these dunite masses are mere bits, having dimensions of only a few inches. Most of them lie conformably in the lamination of the gneiss, but occasionally they cut across this lamination at a perceptible angle. The accompanying sketch (fig. 4 *A*) represents one of these small dunite masses, about a foot thick, surrounded by a sheath of radiating talc about an inch thick, with a thin layer of brownish vermiculite outside.

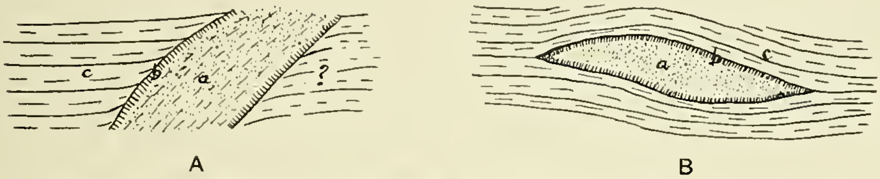


FIG. 4.—Small, lenticular dunite masses intruded into gneiss at Democrat, Buncombe County, N. C.; *A*, uncomformable, and *B*, conformable with the lamination of the gneiss.

The gneiss was distinctly visible on one side of this mass, and its lamination planes made an angle of more than 30° with the plane of contact and the lamination of the dunite. Fig. 4 *B* represents a similar mass conformable with the gneissic lamination.

PERIDOTITES IN MADISON COUNTY.

On Sandymush Creek, along the southeastern border of Madison County, talc-schist and soapstone in small amounts have been observed in a number of localities. In some places, as at Trail Branch (Gudger's mill), the rock has the structure and general appearance of enstatolite (enstatite rock). Very near Trail Branch a bluish schistose talc also occurs on the hill just south of the creek, in Buncombe County.

Two and a half miles below Marshall, on the steep slope rising from the south bank of French Broad River, between Bear and Little Pine creeks, is an outcrop of pyroxenite covering an area of about 10 acres. It consists chiefly of enstatite, and is accompanied by an amphibolite dike. Just below this outcrop, in a meadow, the first specimen of corundum found in North Carolina was picked up on the surface.

At Johnson's ferry, at the mouth of Bear Creek, talc-chlorite-schists outcrop on the steep slopes north of the river. One-fourth of a mile eastward a similar rock occurs associated with considerable chalcedony and radiated fibrous talc. Similar talc-chlorite rock outcrops with a width of 50 feet 1½ miles southwest of the ferry, on the waters of Little Pine Creek.

Peridosteatite, similar to the altered portions of harzburgite at the Rattlesnake mine at Sapphire and also closely resembling the peridosteatite near Bryn Mawr, Pennsylvania, forms the point of a small ridge at the county home, 1½ miles northwest of Marshall, on Walnut Creek. The rock is composed of olivine and talc, the latter probably representing enstatite in the original rock. The olivine is fresh and sometimes forms a large proportion of the rock; in other parts it occurs in smaller amounts and is more or less decomposed. The latter variety has been quarried to some extent for soapstone, and is said to have been used for iron furnace linings in Greene County, Tennessee, about 1868. Blocks containing 15 to 20 cubic feet are said to have been obtained. The outcrop is about 50 feet wide, and the rock shows a slight lamination. Veins of fine, green, scaly chlorite, 10 to 12 inches thick, have been formed across the lamination.

Another soapstone outcrop occurs 1½ miles west of this locality. It is compact, schistose, and somewhat chloritic, but some portions of it have the rust-holes similar to that found at the county home from which the olivine has been weathered. It was also quarried a little for soapstone at the same time and for the same purposes as that described above.

At a number of other places on the waters of Walnut Creek, and north of Walnut Mountains on Big Laurel Creek, schistose talc is found resembling more or less that at the localities just described. Slabs are quarried from these outcrops for local use as fire-place linings, tombstones, etc.

A coarse green amphibolite forms the points of three small ridges 3 miles east of Marshall and one-half mile north of the mouth of Big Ivy River. It is feldspathic in places and contains biotite, passing into mica-diorite. Rough, honey-combed chalcedony is abundant, and crystals of corundum are found weathered out over the surface. One of these crystals, weighing 17 pounds, is shown in fig. 24, p. 208, which is drawn from a photograph.

The belt of peridotites that passes by Democrat, in Buncombe County, crosses the extreme eastern corner of this county. The Carter corundum mine, on Holcombe Branch near the county line, is on this belt, 1½ miles north of Democrat. It is in the midst of an area of yellowish to dark-green dunite which outcrops with a width of nearly one-fourth of a mile. Chromite grains and green nickel stains are abundant, and the surface is characterized by a stunted growth of pine, as at Webster. The dunite is laminated, and the massive blue and pink corundum occurs in a vein with spinel, feldspar, etc., which is developed approximately at right angles to the lamination. The peridotite mass seems to have a blunt lenticular form.

Two and a half miles northeast of the Carter mine, on Terry Fork, 2 miles above its mouth, is a massive, dark-green to almost black serpentine, with some soapstone and chlorite, in an outcrop about 200 feet wide. Two miles west of this, on Paint Fork a mile above the mouth of Terry Fork, serpentine of lighter color occurs in an outcrop more than 100 feet wide. Portions of this mass contain abundant remnants of olivine in small, transparent grains. Some radial structure is also developed along the joints. Two hundred yards east of this locality an unaltered dunite occurs in an outcrop about 50 feet wide, in the creek. The joints show a highly developed radial structure, and also contain chlorite and feldspar intermingled, as at the Carter mine. An outcrop of gneiss occurs in the midst of the dunite. One mile northward and 1½ miles south of Paint Gap, serpentine occurs one-fourth mile east of the road. This rock also contains small remnants of the original olivine which are visible in the hand-specimen. The outcrop is about 30 feet wide. A mile south of the gap and one-half mile east of the road narrow outcrops of talc-schist occur.

PERIDOTITES IN YANCEY COUNTY.

In line with the peridotite masses at the Carter mine and along Paint Fork, soapstone occurs at several places on the mountain just north of Paint Gap. At the north base of the mountain, on Possumtrot Creek a mile above its mouth, serpentine occurs with talc and chlorite. A large outcrop of serpentine also occurs a mile northeast of this, at Neal's store on Bald Creek, one-fourth mile below the mouth of Possumtrot Creek. Three miles north of Bald Creek, soapstone outcrops occur just west of Caney River. Farther northward and northeastward no peridotites or related rocks have been observed.

Another line of outcrops begins, however, 4 miles northwest, on the northern slopes of Sampson Mountains. Half-way down from the gap is the Hayes corundum mine, where three peridotite masses occur very near each other in the gneiss. Enstatolite (enstatite rock) is apparently the predominating rock, but, by the introduction of olivine, it passes into harzburgite and dunite. Corundum occurs along the borders in coarse chlorite and associated with some margarite. An intrusive, fine-grained diorite was encountered near the peridotite in mining. Outcrops of enstatolite, with some olivine-bearing portions, occur northeastward down the mountain slopes to Bald Mountain Creek at Hensley. The enstatite is often altered to talc on the surface. Similar talcose rocks, frequently showing the original structure and appearance of the enstatolite, were found in several places in the continuation of this direction northeastward for 4 miles up the slopes and almost to the summit of Bald Mountains, on the North Carolina-Tennessee boundary.

Two miles east of the principal line of peridotite masses to which the serpentine of Possumtrot and Bald creeks belong, several outcrops of peridotite occur, on Banks and Price creeks. Normal dunite, containing considerable chromite, occurs 3 miles south of Caney River, to the east of Price Creek on a small tributary. Radial minerals are highly developed in the joints. Independent masses of dunite and serpentine about 500 feet apart occur 2 miles south of Caney River on Banks Creek. A short distance northward a dunite outcrop about 300 feet wide, with north-south lamination, forms the summit of a small elevation known locally as "Mine hill." Half a mile northeastward, down the creek, a very irregular dunite mass occurs, composed partly of fresh dunite but altered in other portions to massive serpentine. The outcrop has a very peculiar form, somewhat like the figure 9, with the top of it solid and lying to the east, while the narrow appendage curves toward the west and north. It occupies an area of about an acre, and the broader eastern portion forms a little barren knob.

West and northwest of Burnsville, 1½ to 2 miles, narrow talc outcrops occur on the summit and slopes of Green Mountains. Most of this rock is schistose, but portions of it have the structure and appearance of fine-grained pyroxenite, and have doubtless been derived from some such rock.

Three miles northeast of Burnsville, on Mine Fork of Jack Creek, a large lenticular mass of harzburgite forms two small hills, one on either side of the creek. The more prominent one is known locally as "Mine hill." The outcrop is about one-half mile long and has a maximum width of about 500 feet. The greater axis of the mass lies N. 30° E. The north end is blunt and rounded, while the south end tapers to a sharp point. The rock is a harzburgite composed of olivine and bronzite, the latter partly fresh, partly altered to talc, though still retaining the appearance of the

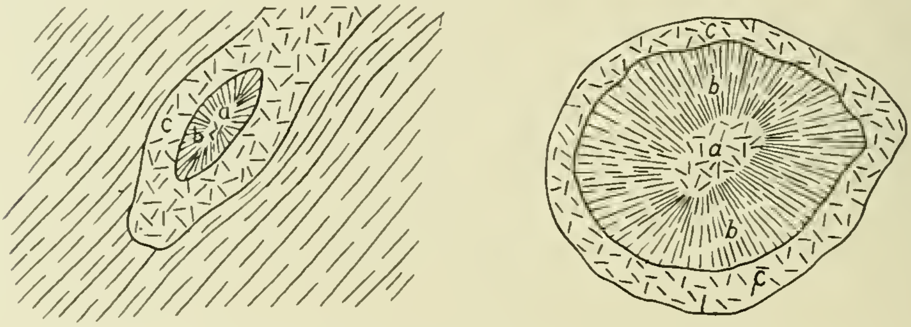


FIG. 5.—Oval and elongated talc cyanite nodules, found 3 miles northeast of Burnsville, Yancey County, N. C.

original mineral. Chromite is abundant in grains throughout the rock, and is segregated into larger masses in places, some of which have been mined to a slight extent. A quartz vein 4 feet thick and traceable for a distance of 100 feet is found in the peridotite just north of the ford of the creek, on the hillside. Along the northwestern border, pegmatite 20 feet thick outcrops in heavy ledges.

One-fourth mile below this large mass, two very small outcrops, but a few inches in diameter, occur in the road (fig. 5). These resemble in some respects the little dunite masses near Democrat, in Buncombe County. One is oval in form, the other is narrow, elongated lens-shaped; both are composed of talc in coarse interlocking blades (*a*) in the interior and of coarser radiating blades (*b*) outside. Surrounding the nodules next the inclosing gneiss is a thin sheath of cyanite (*c*) in interlocking blades. The gneiss at this place is quite schistose, and these masses occur alongside a distinct zone of crushing and faulting.

Five miles north of Burnsville and 2 miles south of Toe River, on Pigpen Creek, dunite forms a barren rocky area on the hillside near the road. Near the river numerous fine-grained, dark, basic dikes intersect the gneiss.

Six miles northeast of Burnsville, in a direct line, dunite forms an oval mass about 300 by 700 feet at the foot of Chestnut Mountain, the knob at the eastern extremity of Green Mountains. This is one of the finest examples of typical dunite in the State. It forms a spur jutting out to the south with an elevation of about 150 feet above the valley, and the surface is entirely barren except for the little bunches of sedge that grow in the joints where some soil has lodged. It is a remarkably uniform olivine rock with chromite grains evenly disseminated through it. About a foot of radiating and interlocking talc forms the border, and the whole is enclosed in mica-schist.

Seven miles southeast of Burnsville, on the ridge just north of Browns Creek, a mass of enstatolite, composed of radiating enstatite largely altered to soapstone, occurs in an outcrop about 50 feet wide. It is bordered by chlorite, and corundum crystals 2 or 3 inches long are found in the decomposed gneiss within 2 or 3 feet of the contact. Nearly a mile east of this, on the same ridge near South Toe River, peridosteatite forms a large part of the small knob that is locally known as Bailey Mountain. The rock is composed of coarse-bladed talc with exceedingly large olivine grains, similar to but of much coarser texture than the peridosteatite at Sapphire and at the Madison County home. The rock is doubtless a harzburgite in which the enstatite has altered to talc (metaharzburgite). It is similar in many respects to the harzburgite of the most easterly outcrops near Balsam Gap, Jackson County, but the talc is coarser than the enstatite there and in larger proportion. The olivine, like that of Balsam Gap, frequently shows lustrous cleavage faces 5 to 6 inches in diameter and of rounded irregular outline. Some of the more talcose portions of this rock have been quarried for local use in fireplaces, etc.

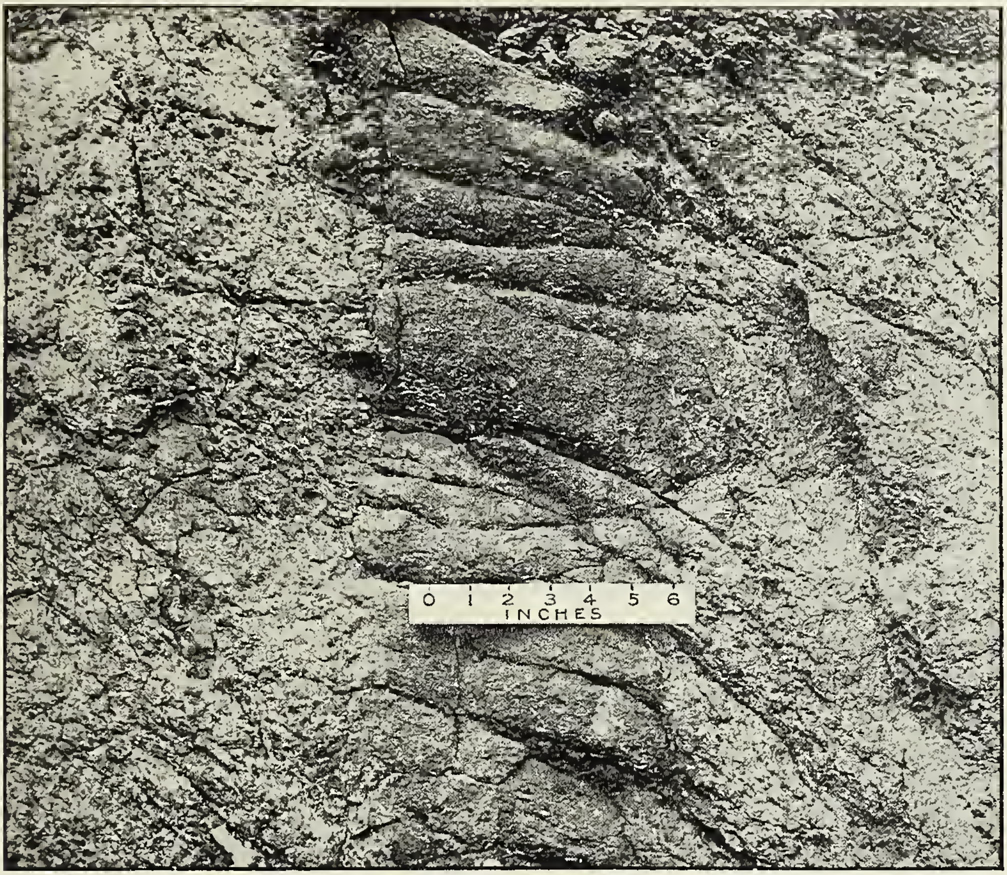
On the east side of South Toe River, about a mile north of Bailey Mountain, on the western slope of Fawn Knob, fine, scaly, massive soapstone forms an outcrop about 100 feet wide, accompanied by some chlorite. Relics of Indian quarrying and pot-making are found here. Typical laminated dunite occurs in two outcrops one-fourth mile northeast of the soapstone. Similar soapstone also forms heavy ledges along the eastern border of the dunite.

A large peridotite outcrop occurs just north of the ford of South Toe River, 7 miles east of Burnsville and 1½ miles east of Micaville. The greater part of the rock is laminated dunite, bearing some nickel stains in the joints. By the introduction of enstatite it passes in places into harzburgite and pyroxenite. The outcrop has a maximum width of 300 to 400 feet and is about one-fourth mile long. A large part of the surface is barren and rocky.

PERIDOTITES IN MITCHELL COUNTY.

An oval mass of dunite about 300 by 600 feet occurs on the "Woody place," 2 miles south of Bakersville, forming a very barren rocky hillside. Much of the rock is laminated, and the outcrop has an appearance very similar to that at Webster, and also to the locality last described. A little enstatolite is found, and chalcedony, both cellular and compact translucent, is scattered over the surface. Nickel silicates occur in thin incrustations, and chromite is sparingly disseminated through the rock. One mile south of Bakersville a small mass of dunite outcrops in and near the road. Another small outcrop, represented by a surface exposure chiefly of soapstone with a little peridotite, is found in the western border of the town of Bakersville, just north of the road leading down Cane Creek.

Pyroxenite (enstatolite) about 20 feet wide, with radial borders, has been prospected for asbestos on White Oak Creek, 1½ miles southeast of Bakersville. Fragments and small crystals of corundum are found on the surface. Similar rock is said to occur one-half mile northeast of this locality. Talc-schist, still partly retaining the structure of pyroxenite, outcrops with a width of about 100 feet at Cane Creek church, 3½ miles east of Bakersville.



A, DIKE OF DUNITE IN HARZBURGITE, NEAR BALSAM GAP, JACKSON COUNTY, N. C.

B, PERIDOTITE PROMINENCE NEAR BALSAM, JACKSON COUNTY, N. C.

Dunite occurs in a small mass near the summit of Grassy Ridge Bald, 7 miles northeast of Bakersville and one mile from the State line. Three miles south of this a large barren outcrop is said to occur near the head of Henson Creek. Further down the creek, 1½ miles from its mouth, outcrops of talc-schist occur.

A large, irregular area of dunite occurs along the North Toe River between the mouths of Squirrel and Roaring creeks, 6 miles south of Cranberry. The outcrop is 150 to 200 feet wide and nearly a mile in length. Chromite forms large, irregular masses in some portions of the rock, and chrysotile is developed in long fibers near the north end of the exposure, just below the mouth of Squirrel Creek. A small dunite mass occurs near the river on the west side, one-half mile north of the mouth of Squirrel Creek, and a larger area is exposed a mile east of this on the western slope of Haw Mountain. An enstatite-talc outcrop also occurs near the head of Squirrel Creek, at Lineback.

At Bellvue, on the summit of Fork Mountain, 2 miles south of Cranberry, dunite again appears in an outcrop about 200 feet wide, largely altered to serpentine and talc. A strip of talc can be traced about one-fourth mile north of the principal outcrop.

For a distance of 16 miles northeast of Cranberry no peridotites or similar magnesian rocks have been found. The region is occupied by irregular areas of gneiss and the less metamorphic rocks of the "Ococe" formation, all intensely folded and faulted. Massive igneous rocks of granitic and dioritic aspect also occur.

PERIDOTITES IN WATAUGA COUNTY.

Dunite forms a small outcrop near the road 2½ miles west of Boone, on the headwaters of Brushy Fork. From this point northward, disconnected masses of peridotite and pyroxenite (enstatolite) occur at short intervals along the upturned edges of the gneisses on the western slopes of Rich Mountain for a distance of 4 miles. Pyroxenite predominates in most of these outcrops, and it is usually much altered to talc; but dunite occurs in an outcrop 100 feet wide, 5 miles northwest of Boone in a direct line, and one-half mile west of the gap in Rich Mountain through which the road passes. The rock forms a prominent point of a mountain spur near the road. A heavy outcrop of enstatolite occurs along the eastern border of it. Large masses of chromite occur in the dunite, and a little mining has been done here, as described by Mr. H. B. C. Nitze.[9]

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[9] Bulletin North Carolina Geol. Survey, No. 1, 1893, p. 212.

Pyroxenite (enstatolite), considerably altered to talc, occurs in several outcrops 4 to 6 miles north of Boone on the waters of Meat Camp and Rittle creeks, west and north of Green Knob. Some of the exposures have a width of 100 feet or more. Talc-schist occurs just east of Rocky Mountain, 5 miles east of Boone. A mile from this locality, on the crest of the Blue Ridge just north of Cook Gap, a talc-serpentine rock is found in an outcrop about 50 feet wide and 3 or 4 times as long. Talc, with fine radiating actinolite, is the predominant rock, but there are also large masses of dark-green serpentine, the only occurrence of this rock observed in this belt north of Cranberry. One-fourth of a mile northeast of this a talc outcrop of about the same dimensions is found on the eastern slope of the Blue Ridge.

PERIDOTITES IN WILKES COUNTY.

The only outcrop of this nature thus far observed in Wilkes occurs 1½ miles northwest of North Wilkesboro on Reddies River. It is a mass of serpentine, 100 to 200 feet in width, and traceable in a northwest-southeast direction for a distance of about 600 yards. Near the southeastern end it broadens out and forms a small hill, and is here within a hundred yards of the river. The rock is composed entirely of serpentine, with seams of chrysotile from one-fourth of an inch to an inch thick. The rock is more or less decomposed to a depth of 10 to 20 feet, but below this hard, compact serpentine was encountered suitable for building purposes.

PERIDOTITES IN ASHE COUNTY.

Great cliffs of harzburgite occur on the southern slopes of Black Mountain, near the Ashe-Watauga County line, 3 miles up the Middle Fork of Elk Creek from Todd (Elk Cross-Roads). From the almost inaccessible cliffs great boulders have rolled down the slopes into the valley. In most of the rock enstatite and olivine occur in about equal amounts, though some masses of the pure enstatite rock were observed. It varies from fine-grained olivine and small-bladed enstatite to a rock of extremely coarse texture. Some of the boulders show segregations of enstatite into masses 3 or 4 inches in diameter alternating with similar areas of olivine. The enstatite, as usual, is more or less altered to talc in portions of the rock, and some chlorite also appears in most of the masses.

Harzburgite again forms a very large area on Bee Ridge, an eastern spur of Elk Ridge, 7 miles southwest of Jefferson. The outcrop has a maximum width of about 1,000 feet, is about one-half mile or more in length, and is distinctly forked at its southern extremity. A considerable part of the rock along the eastern border is now compact soapstone, doubtless altered pyroxenite, and has been quarried for linings for the Ore Knob copper furnaces, as well as for local use in fire-places, for tombstones, etc. The harzburgite on top of the ridge is laminated in a direction parallel to the principal axis of the mass, N. 23° E. At the eastern point of the forked southern extremity the rock is composed of enstatite blades 3 or 4 inches across and olivine grains one-half to three-fourths inch in diameter. Soapstone has also been quarried from a number of outcrops that occur at intervals for 2½ miles northward, to the headwaters of Buffalo Creek. A mile west of this line of outcrops, in the gap of Elk Ridge where it joins Bluff Mountain, soapstone is found exactly similar to that accompanying the peridotite at Bee Ridge. Large boulders that have rolled down the western slopes have been quarried for local purposes and for the furnaces at Ore Knob.

Soapstone is found south of Jefferson, on the north slopes of Nigger Mountain, in a large outcrop from which about 300 cubic feet of stone have been quarried and sawed into slabs. Chlorite in large scales and plates occurs in considerable aggregates, and portions of the rock are full of small, rusty cavities containing an ocherous powder. From its close resemblance to the more weathered portions of the harzburgite outcrops, it seems probable that this is but an altered facies of that rock. Rock of the same character occurs in Phœnix Gap and 300 yards south of the gap, 2 miles northeast of Jefferson, in outcrops about 100 feet wide. Numerous interlocking blades of black hornblende occur in portions of the rock at the gap.

A compact chlorite rock, forming two belts of outcrops on Little Phœnix Creek, 1 to 2 miles north of the gap, may possibly be related to the peridotites. The rock contains numerous small grains and nodules of carbonates, and has short, white, asbestiform minerals developed in the slickenslides. Soapstone, also, similar to that at Phœnix Gap, is said to occur to the northeastward on Long Shoal Creek.

With the exception of the talcose and chloritic rocks just described, no peridotites or other magnesian formations have been found for a distance of 16 miles northeastward from Jefferson.

PERIDOTITES IN ALLEGHANY COUNTY.

A small outcrop of talc-schist is found on one of the spurs of Peach Bottom Mountains, 7 miles southwest of Sparta and 3 miles west of Whitehead. About 3 miles southwest of Sparta and 1 miles northeast of Whitehead, soapstone occurs with rust-holes, as though from the weathering out of olivine, and an exactly similar rock is found a mile eastward in the bend of Little River above the mouth of Pine Swamp Creek.

An olivine-talc rock, or peridosteatite, which is doubtless an altered harzburgite, occurs in a large outcrop at the head of Glade Creek, 2 miles south of Sparta. It closely resembles the rock of this nature found at Sapphire, at the Madison County home, and elsewhere. Talc largely predominates throughout the mass, and is almost the sole constituent of the rock where it tapers to a point at the eastern extremity. It has been quarried as soapstone for local use in fire-places, etc. Westward it broadens and becomes olivine-bearing, though talc still largely predominates. Some carbonates are developed through the mass, and most of the rock is somewhat laminated. The weathered surfaces are often knotty, like the peridosteatite west of Philadelphia, from the projecting masses of olivine. Chlorite is considerably developed in scaly aggregates and plates up to 2 inches in diameter. Radiating actinolite occurs in clusters of green crystals in portions of the talc.

A peridosteatite very similar to the last, except that olivine is the predominant constituent, forms an oval mass 200 by 400 feet in area, 4 miles northeast of Sparta and half a mile southeast of Edwards Cross Roads, just north of Little River. A grayish, radiating mineral, in compact mass, probably anthophyllite or cummingtonite, and more or less chlorite are developed here. A mile eastward, across the river, the same kind of rock occurs, with rather more knotty talc and more of the radiating mineral. Another similar mass occurs one-fourth mile farther eastward, continuing for half a mile up to "Bald Hill," where it forms a barren knob. The rock here contains much talc with the habit of coarse-bladed enstatite. The proportion of olivine to talc varies considerably, almost producing the pure types of both in some portions of the mass. Some green nickel stains were observed.

Talc, with cavities containing ocherous residue, possibly from weathering out of olivine, forms an outcrop 150 feet wide at Ennis, 2½ miles east of the above, on Crab Creek 1 mile above its mouth. The inclosing rock is mica-schist with some gneissic laminæ. Two and one-half miles northeastward peridosteatite composed of about equal parts of olivine and talc forms a laminated outcrop about 200 feet wide, extending across the State line into Virginia. It is said to occur in several places between this place and Ennis, and is known at intervals northeastward for 15 miles in Virginia.

PHYSIOGRAPHY AND ECOLOGY OF THE PERIDOTITES.

The peridotite outcrops, though very numerous in certain sections, are not sufficiently large to have any marked effect upon the general physiographic characters of the region. The geologist and the prospector soon recognize certain features, however, as more or less characteristic and often find them useful in determining the location and extent of the outcrops. These features may be conveniently classified under three heads: (1) *topographic forms;* (2) *superficial aspects;* (3) *ecology.*

TOPOGRAPHIC FORMS.

The massive periodites are considerably more resistant to the forces of denudation than the enclosing gneisses, and hence the larger outcrops frequently form prominent little knobs and peaks when they occur on the crests of hills or mountains, and cliffs or the points of projecting spurs when on the slopes. Where the outcrops occur in the valleys they often constitute the backbones of little hills and ridges that stand noticeably above the general level of the adjacent gneisses.

When, however, the outcrops are very narrow and much sheared, as they frequently are when narrow, instead of producing forms that indicate a high degree of resistance, they mark planes of evident weakness in the rocks. On this account such thin strips are sometimes very difficult to trace by their outcrops, as they are generally followed by little valleys and cross the ridges in low gaps. In such cases the peridotite is usually too thin to have any appreciable effect upon the topography; while, on the other hand, it occupies a shear zone in the gneisses, along which faulting and crushing have taken place so extensively as greatly to impair the normal resistance of the gneisses themselves.

These narrow strips sometimes connect the larger lenticular masses with one another in a continuous line for several miles; and hence the prominences due to the larger bodies of peridotites often alternate, along the line of outcrop, with depressions of the surface, in which the thin strips of the peridotites or their sheared alteration products may be seen at intervals where exposed by the wash of the streams.

Similar weakness of the gneisses from shearing causes unusually deep decay about the borders of the larger peridotite masses, thus favoring rapid erosion and emphasizing still more the contrast of the gneisses with the more resistant peridotites.

Another topographic form produced to a certain extent by the peridotites is that resulting from landslides. On the gentle slopes of the southern Appalachians landslides of great magnitude never occur, and even small ones are rare. Two miles southwest of Balsam Gap, Jackson County, however, on a mountain side, both above and below the railroad, may be seen several small but well-marked landslides in the peridotites (Pl. XV, B). The rock of this outcrop is harzburgite, and the large amount of talc formed from the alteration of the enstatite, and possibly from the olivine also, has made the joint planes and planes of contact with the gneisses exceedingly slippery. The talcose belts are also practically impervious to water, and the ground-water naturally accumulates along them, still further reducing the friction.

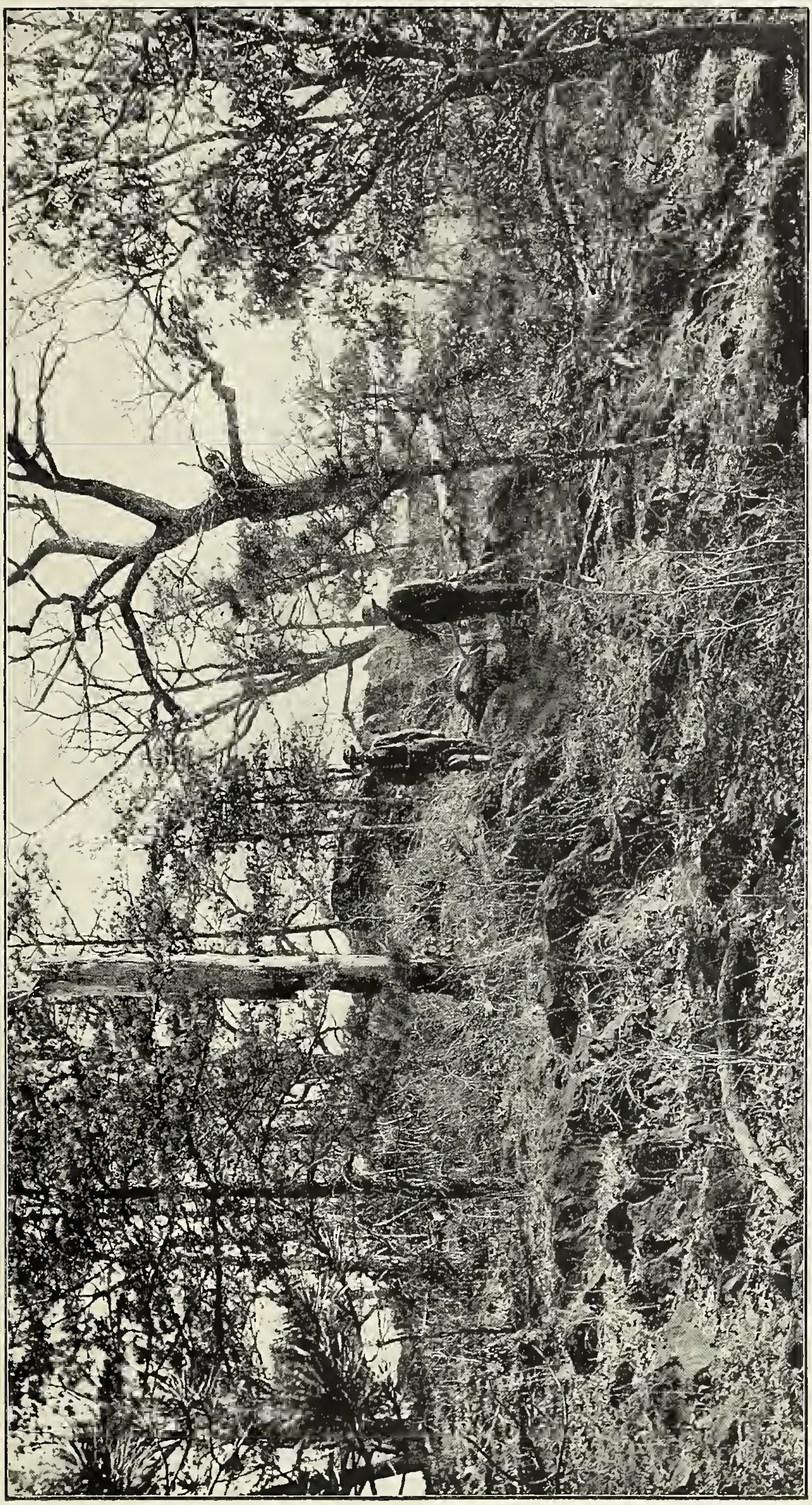
These have undoubtedly been the chief causes of instability, for the gneisses, even on steeper slopes, have remained perfectly firm. This view is further confirmed by the experience of the miners in working the corundum deposits that are often associated with the peridotites. In sinking shafts, and more particularly in tunneling, it is found very difficult to timber the workings safely on account of the tendency of the peridotites to slip along these lubricated joints.

SUPERFICIAL ASPECTS OF THE PERIDOTITES.

The barren, rocky surface and the characteristic dull-brown color often render the peridotite outcrops somewhat conspicuous, particularly in a region that is almost universally covered with soil which bears abundant vegetation in forest and field. Where the slopes are steep enough to expose occasional cliffs of gneiss, the light-gray color of these rocks sufficiently distinguishes them from the rusty peridotites, even when seen at a distance.

The weathering of olivine (its decomposition on exposure to the weather) produces hydrous iron sesquioxide (limonite), silica (both quartz and chalcedony), and the carbonates of iron and magnesium. Most of the carbonates are usually carried away in solution. The ocherous residuum forms a soil incapable of supporting a vegetable cover, and hence rapidly washes away, leaving most of the outcrop bare (Pls. IX, XI, XII, and XXV). Erosion is also frequently accelerated by the elevation of the prominences and steepness of the slopes formed by the peridotites.

Scores of illustrations of this marked barrenness of surface might be enumerated from the great belt of peridotites that stretches from Alabama into the Gaspé Peninsula and to the western shores of Newfoundland. A few quotations from published descriptions of some of the most prominent areas will serve to emphasize this striking characteristic.



OUTCROP OF PERIDOTITE AT BUCK CREEK, CLAY COUNTY, N. C., SHOWING SEMI-BARREN SURFACE.

Mr. R. W. Ells, in a "Report on explorations and surveys in the interior of the Gaspé peninsula, 1883," says:[10]

> Among the prominent features of the Shickshock range are the two barren hills of serpentine, the one on the eastern extremity, overlooking the forks of the Ste. Anne River, and known as Mount Albert; the other 12 miles west, on the Solomon branch, and called by Sir W. E. Logan the South Mountain.

In the same report Mr. A. P. Low adds the following description of the appearance of Mount Albert:[11]

> The summit is 3,000 feet above the bed of the river and 1½ miles distant. The top of Mount Albert is flat, and is rent by a deep gorge on the east side, which, near its head, splits into several smaller ones. The sides of the gorges are quite destitute of vegetation, and the bare serpentine rocks are weathered to a light buff color. On top of the mountain blocks of serpentine are scattered around, and are partially covered by a thick growth of mosses and lichens. Sheltered places are occupied by a stunted growth of black spruce (*Abies nigra*), which rarely attains a height of ten feet. The whole surface has a dead appearance, and reminds one of the pictures of the moon.

Mr. Low describes the rocks as "chiefly olivine more or less changed into dark green serpentine." All the rock seen on Mount Albert was altered into serpentine.[12]

Mr. William Glenn[13] describes the appearance of the great serpentine areas about the Black Lake mines of Quebec as follows:

> For fifteen minutes before reaching Black lake, it is noticed that the train is moving through a low, mountainous country which presents a barren and inhospitable aspect. If he be at all familiar with such a landscape as is before him, he will be convinced that he is passing through a comparatively enormous field of serpentine. Such distressing poverty of foliage, the sharp crest lines of bleak and bare hills, such want of animate nature, all are expressive of that poverty of soil (and of no soil) typical of those rocks. But as the climate is cold and moist, the whole region is carpeted with cryptogamous plants, the lowly organisms which ask so little of mother earth. . . . One here is passing through the chromic iron field; and just beyond . . . . the great asbestos (chrysotile) quarries come into view.

The numerous serpentine areas of southeastern Pennsylvania and Maryland were well characterized by Mr. J. Finch[14] nearly a century ago in describing the serpentine areas about West Chester, Pennsylvania:

> It [serpentine] is universally distinguished by its sterility, and the fields where it occurs have received the emphatic title of "Barrens."

The well-known Bare Hills near Baltimore are serpentine hills, and the name applies equally well to numerous others throughout the State of Maryland.

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[10] Geol. Survey, Canada, Report of Progress, 1882-3-4, pp. 1-34E.

[11] Ibid., p. 7F.

[12] Ibid., p. 19F.

[13] Seventeenth Ann. Rept. U. S. Geol. Survey, 1895-6, Pt. III, p. 271.

[14] Am. Jour. Sci., 1st series, Vol. XIV, 1828, pp. 15-18.

The peridotite outcrop at the Laurel Creek corundum mine, at Pine Mountain, Georgia, is thus described by Mr. Francis P. King:[15]

> From this [map] it may be seen that the formation occupies two small hills. These stand out conspicuously to an observer on account of their rough, barren nature and the rusty, ocher color of their rocky surface (so characteristic of chrysolite formations), offering, in external appearance, a sharp contrast to their environments.

All the larger outcrops in North Carolina, and many of the smaller ones, exhibit this characteristic to a greater or less degree. In the most conspicuous cases this character is referred to in the foregoing descriptions of the distribution. Some of the notable instances are the outcrops at Buck Creek, in Clay County; Corundum Hill, in Macon; Carter mine, in Madison; Mine Fork and Chestnut Mountain, in Yancey; and the Woody place, in Mitchell.

Exceptions to this barren condition are found where the outcrops occupy slopes over which soil from higher ground may creep down. Under these conditions, the whole surface may be occupied by vigorous forest growth, in which, however, numerous resistant ledges of peridotite may often be found projecting through the soil.

Seepy places sometimes occur about the borders of the large peridotite outcrops, owing to the impervious shield of talcose rock usually formed along the contacts. This feature has occasionally proved useful in determining the limits of outcrops where, on account of soil-creep or other causes, the rock exposures were insufficient.

ECOLOGY OF THE PERIDOTITE AREAS.

From the foregoing descriptions of the superficial aspects of the peridotites, it is evident that they are usually characterized by more or less peculiar plant groupings. This is clearly brought out by the recent studies of Professor John W. Harshberger,[16] of the University of Pennsylvania, who studied the flora of ten representative serpentine barrens in southeastern Pennsylvania. The following quotations are taken from Professor Harshberger's article:

> The flora of the serpentine exposures, which are always more or less barren in appearance, is peculiar. The eye of the botanist, or of the observant layman, is at once arrested by the association of the characteristic species which make up the serpentine flora, because it is sharply demarcated from the flora of the surrounding country. The botanist can identify the serpentine areas, where the rock is covered by a shallow soil, by the vegetation alone, for the species which are characteristic plants, although occurring elsewhere in the

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[15] Bulletin Geol. Survey of Georgia, No. 2, 1894, p. 78.

[16] Science, Vol. XVIII, p. 339, 1903.

region, are here grouped together in such a manner and in such number, as to delimit sharply these areas from the surrounding country. The serpentine plants taken together, therefore, form islands set down in a sea of other vegetation with a boundary as well characterized as the shore of an oceanic island, and with tension lines induced by the struggle for existence as sharply drawn as the shore line against which the storm waves beat. The sharp delimitation of the boundaries of the serpentine areas is emphasized by the fact that these areas are rarely cultivated, but are surrounded by rich cultivable land from which the original vegetation has been removed by man. Many of the plants found on the serpentines have survived, therefore, such vicissitudes and have persisted on the barrens, while the same species have been exterminated in the cleared land. This fact, howver, does not militate against the unique character of the serpentine flora, because the forest which exists on the soils other than the serpentine is of an open type with the presence of a large number of shade-loving plants, such as *Sanguinaria canadensis* L., etc., which are not found as constituents of the barren flora. . . . .

Ecologically the flora of the serpentine barrens belongs to the mixed deciduous forest and barren treeless formations. . . . . These formations and associations . . . . are controlled largely by edaphic conditions. Thus the forest type exists where the geologic formation is covered by a surface layer of soil of some depth. The barren treeless formation exists where the serpentine rock is exposed with little or no surface soil. Where springs occur and the soil is wet, the character of the associations is determined by the amount of soil water. . . . .

One fact is proved abundantly by a study of the flora of the serpentine barrens, and that is that the chemical character of the soil derived from a disintegration of the serpentine plays an unimportant part in the distribution of the plants mentioned. The distribution of such species is due rather to the physical conditions of the soil, especially with reference to water conductivity and water storage capacity (edaphic conditions).[17] The variation in the character of the plant association, described above, is in the main due to the character of the soil. If the soil is present as a well-marked surface layer, then tree associations are found: if on the other hand the rock is exposed, herbaceous associations are the rule. The surface layers of serpentine rock are broken by weathering into angular fragments. which, lying loosely together, permit the percolation of the rain water down into the seams of the underlying rock. Such exposures, therefore, support plants that have adapted themselves to living in dry situations and have structural arrangements which prevent a rapid loss of water.

These descriptions may be taken as typical of the distinctness with which the flora of the peridotite areas is demarcated throughout the Appalachian region. This is particularly true of all the larger areas, but is no less distinctly marked in great numbers of the smaller outcrops. Ecological studies have not been made in other parts of this region. These would undoubtedly show considerable variation in the plant associations with climate and physiography, but the same general principles would doubtless be found to hold true as in Pennsylvania.

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[17] Conditions at Webster (see p. 96) seem to indicate that this is not always the case.

CHAPTER III.

PETROGRAPHY OF THE PERIDOTITES AND ASSOCIATED BASIC MAGNESIAN ROCKS.

In the petrographic studies following no attempt has been made to describe minutely the characters of all the outcrops of peridotites and related rocks that were visited and mapped.

The field work was begun in the southern part of the belt, where the largest and most important outcrops occur; and hence the more detailed and complete studies of some of the areas of this region, particularly the Buck Creek, Corundum Hill, and Webster areas. In general, thin sections were prepared from only occasional typical rocks of other localities, or from such interesting facies as were encountered from time to time in the field work.

SHOOTING CREEK REGION, CLAY COUNTY.

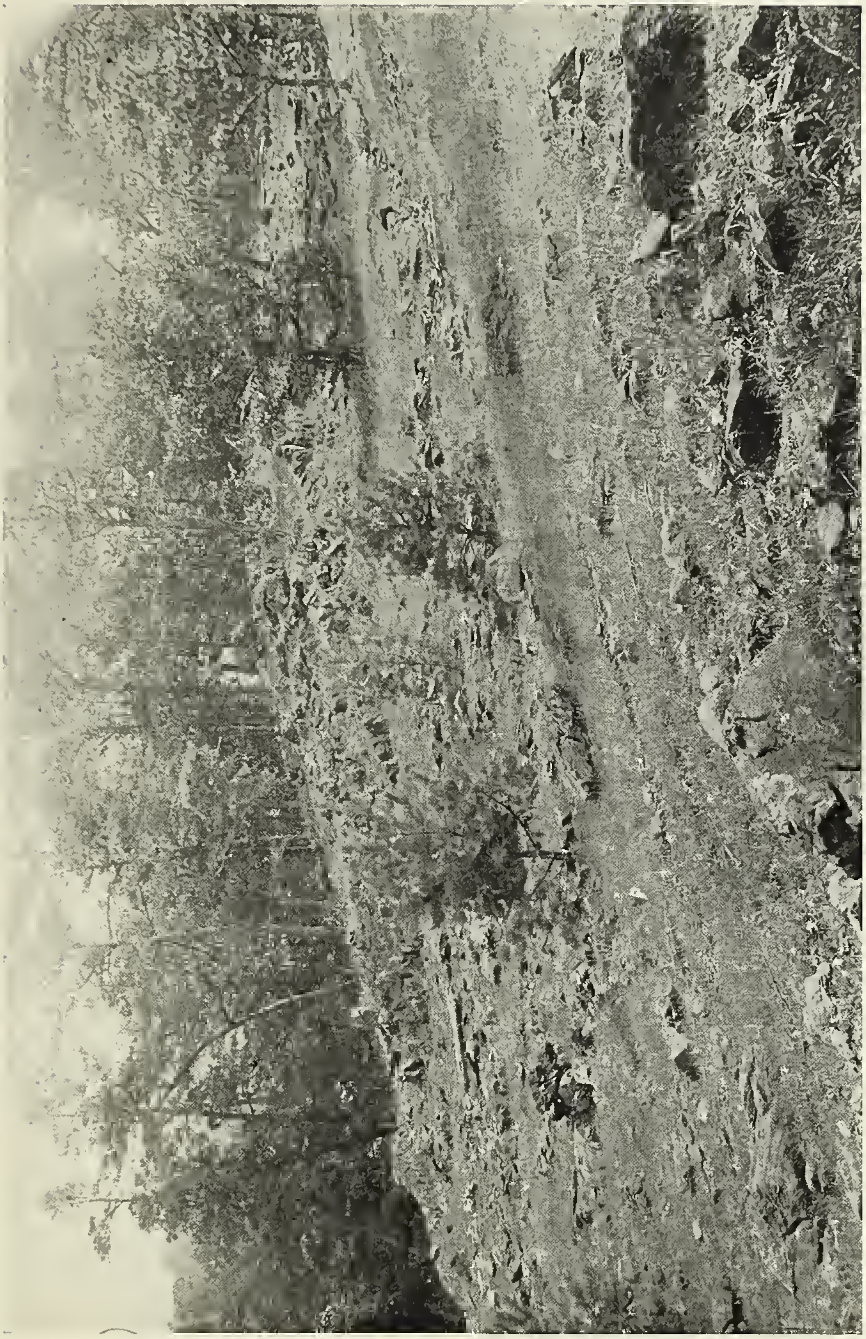
A mass of peridotite extends from near Elf, southwestward about 2 miles, across Shooting Creek (see map, fig. 1, p. 37). A smaller mass $1\frac{1}{2}$ miles long lies just east of the southern portion of this. Dunite, pyroxenite, amphibole-peridotite, amphibolite, and gabbro occur in these outcrops. So far as these have been studied in thin section, their descriptions are given below.

About 5 miles east of Elf a line of peridotite outcrops passes near Shooting Creek post-office, extending somewhat disconnectedly from about the junction of Eagle and Muskrat forks southwestward across Shooting Creek mountains and down Bell Creek into Towns County, Georgia.

ELF DUNITE.

The sections were prepared from specimens collected near Samuel Hogsed's near the middle of the larger area, shown on the map (fig. 1).

Megascopic characters.—The rock is of medium- to fine-grained texture, and varies in color from dark-green to light yellowish green. Broad reflecting surfaces due to the cleavage of the olivine indicate approximately the size of some of the original grains that have become fractured into the present fine-grained condition. Small granules of chromite are



OUTCROP OF DUNITE AT WEBSTER, JACKSON COUNTY, SHOWING BARREN DUNITE SURFACE AND FOREST-COVERED GNEISS.

visible in the hand specimen, and also occasional slender needles of cummingtonite or tremolite.[1]

Microscopic characters.—The granular olivine shows a little alteration to yellow serpentine around the borders and along the fissures of the grains. The serpentine varies in amount in different sections from slight traces to about one-fourth of the rock. The slender amphibole needles exhibit the characteristic cross-fracturing, and basal sections show the amphibole cleavage. Some of them penetrate the grains of olivine, and have evidently been developed at the expense of the latter. Clusters and irregular grains of carbonates are occasionally seen under the microscope. These sometimes surround the magnetite granules and aggregates of magnetite segregated from the altering olivine, and occasionally even enclose grains of the olivine itself. The chromite is usually in smaller grains than the olivine, and frequently exhibits a characteristic coffee-brown translucence on the thin edges or in fractured particles. Secondary magnetite, separated from the olivine in the process of serpentinization, forms numerous small, irregular grains and clusters among the serpentine.

ELF AMPHIBOLE-PERIDOTITE.

The sections were made from fresh material taken from the Ledford tunnel, about 1¼ miles southwest of Elf.

Megascopic characters.—These vary from that of a coarse dappled rock, consisting of large, pale-green olivine grains in a compact dark-green ground, to the massive, dark-green rock in which only a few scales of chlorite and minute light colored veins are recognizable by the unaided eye.

Microscopic characters.—The microscope shows the coarse-grained dappled rock to be remarkably fresh. The large olivine grains are only slightly altered along the borders and cracks to greenish yellow serpentine. Many of the grains show a highly developed cleavage, and serpentinization is often well advanced along these planes when entirely absent from the irregular fissures in the same individual. The only other original constituent of importance is pale-green to colorless actinolitic amphibole, which occurs abundantly in grains and elongated prismatic individuals. Both the olivine and actinolite frequently contain small, rounded and oval grains of yellowish picotite and green pleonaste.

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[1] In this and in all similar rocks described in this chapter, the colorless amphiboles occur in relations exactly analogous with those of Corundum Hill and the Sapphire area, described in the following pages, where there is strong evidence that these slender glistening needles, when monoclinic, are cummingtonite and not tremolite. Optically they are identical, and a delicate chemical test is necessary to distinguish between them as they occur in the mass of the rock. (See also p. 124.)

The secondary minerals observed, besides the small amount of serpentine described above, consist of only a few laths of chlorite and numerous small grains of magnetite. In the darker and more altered portions of the rock, however, there is great development of chlorite. In fact, this mineral entirely replaces the amphibole in some sections and shows considerable encroachment upon the olivine. In these there is also much more secondary magnetite segregated into clusters and streaks through the other secondary minerals.

ELF TROCTOLITE.

The sections here described were made from specimens collected on the eastern border of the smaller peridotite area (see fig. 1) one-half mile south of Hogsed's.

Megascopic characters.—The rock is distinctly banded, being composed of dark-green, compact layers from one-sixteenth inch to 2 or 3 inches thick, alternating with the very light-colored to almost pure white layers of one-sixteenth to one-fourth inch in thickness.

Microscopic characters.—The original minerals of the dark bands are found to be olivine and occasional plates of hypersthene, and of the light-colored bands a plagioclase feldspar, probably anorthite. The olivine exhibits the characteristic appearance of the peridotites, a uniform granular texture, somewhat altered to serpentine, and in places passing over almost entirely into the secondary mineral. The enstatite, though less abundant than the olivine, occurs in much larger individuals, and appears typically in broad plates with well developed prismatic cleavage and marked pleochroism. The feldspar shows but little clouding or tendency to kaolinization.

More important than the essential constituents, however, in some sections, are the peculiar groups of subordinate minerals along the contacts of the olivine and the feldspar. Three-ply *corrosion mantles* of remarkable extent have been developed in these places; but as similar phenomena are more fully described in connection with the Buck Creek troctolites (see p. 79), these will be but briefly referred to here. The three zones or layers of minerals composing these mantles, beginning with that next the olivine, are: (1) enstatite, which is developed in broad plates in many places, with the characteristic optical properties of the species; (2) diopside, in smaller individuals, but distinct; (3) finely fibrous, pale-green amphibole, intimately intermingled with pleonaste. The spinel minerals present a series ranging in color from the dark brown of picotite to the light green of pleonaste, but only the latter occurs in the finely vermiculate form intermingled with the fibrous amphibole of the corrosion mantles.

These corrosion minerals are often developed to the entire replacement of either the olivine or the feldspar, when one of these had occurred in unusually small amount. Small grains and ragged patches of pleonaste are also frequently found in large numbers in the feldspar and olivine adjacent to these corrosion products along the contacts.[2]

ELF AMPHIBOLITE.

Amphibolite, passing into diorite facies and accompanied by gabbro and gabbro-diorite, occurs in a number of dikes cutting the peridotites and adjoining gneisses at Elf, on Shooting Creek, Clay County (see fig. 1).

Megascopic characters.—The rock is frequently schistose, and varies in color from light greenish gray to greenish black; typically it is grass-green to emerald-green. With the introduction of an appreciable amount of feldspar, the color naturally becomes much lighter. Corundum, usually pink to ruby-red in color, though sometimes white, gray, and blue, is frequently present in visible grains and irregular cleavable masses up to 2 or 3 inches in diameter. The contrast of bright green and red, even on exposed surfaces of the rock, is very striking and beautiful.

Microscopic characters.—Pale-green to colorless amphibole is the chief constituent in most of the sections, although feldspar is often present in small amounts and sometimes forms as much as half the bulk of the rock. Corundum is often present, varying in size from minute microscopic particles to large cleavable grains, and is usually colorless. The corundum is as variable in quantity as in size of grains; in most of the sections it is either absent altogether or is found only in minute grains, but occasionally it occurs in such abundance as to constitute more than half the bulk of the rock. In the latter case, the rock has the usual granular "pepper-and-salt" appearance of the feldspathic amphibolites, so closely do the whitish corundum grains resemble the triclinic feldspars that usually occur.

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[2] For comparison a brief description of the microscopic characters of the troctolite occurring on Brasstown Creek, in Towns County, Georgia, about 7 miles southwest of Elf and 1¾ miles north of Young-Harris, is here given.

Microscopic characters.—The section is over half composed of olivine, which is slightly altered to yellowish serpentine, especially along the cleavage cracks. The serpentine contains numerous magnetite granules, particularly along the central portions, marking the position of the original cracks. Plagioclase feldspar (probahly anorthite) occurs in only a few large remnants. Large areas of it have been entirely replaced by the corrosion products. Occasional grains of brown translucent picotite occur.

The corrosion mantles are only two-ply in this rock, and consist of (1) enstatite in broad plates next the olivine, usually nearly colorless; (2) pale-green monoclinic amphibole, in slender needles and narrow laths, usually slightly pleochroic in greenish and yellowish tones, and always associated with much pleonaste in parallel arrangement and irregularly intermingled. As olivine preponderates over the feldspar in this rock, the latter is often entirely replaced by the corrosion minerals. In such cases, the "nests" of minerals replacing the feldspar consist, in some cases, of enstatite alone; in others, enstatite forms the border next the olivine, with amphibole in the center. Picotite grains surrounded by the corrosion minerals show a gradual transition from the dark-brown color in the central portions to the light-green of pleonaste about the borders; among the olivine, picotite does not show this character.

The amphibole is monoclinic, giving inclined extinctions, $\mathfrak{c} \wedge c$, ranging from 15° to 20°. It usually forms elongated prismatic individuals, which in the majority of cases have a parallel schistose arrangement. Basal sections frequently show the development of the unit prism (110), but no terminal planes occur. In some cases of pronounced schistosity, the amphibole shows a decided tendency to fibrous character, fraying out at the ends and altering into chlorite, with the segregation of magnetite in granules and clusters. In the distinctly colored varieties, the pleochroism is: $\mathfrak{a}$ = pale green to colorless, $\mathfrak{b}$ = yellowish green, $\mathfrak{c}$ = pale green, or bluish green to colorless. The absorption is $\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$. When very light colored, pleochroism is either absent altogether or barely discernible. In all these properties it agrees with the aluminous amphibole edenite of the Buck Creek amphibolite (p. 82).

The feldspar, when present, varies from small scattered grains to large coarse-grained areas, equal to or exceeding in amount the amphibole. It generally shows abundant multiple twinning; and, in the more schistose specimens, this is unusually developed, as well as strain phenomena and more or less banding and granulation. The feldspar is sometimes distinctly coarser grained than the amphibole, and frequently contains inclusions of the latter. Kaolinization is almost entirely absent. In the Buck Creek amphibolite, which is entirely similar to this, the feldspar was found to be anorthite (see p. 84).

The corundum grains are colorless and entirely irregular in outline. The larger ones show well-marked cleavage in two directions approximately at right angles to one another, and frequently exhibit the uniaxial cross and negative optical character of the mineral in convergent polarized light. It shows the characteristic prominent relief of high mean refraction and the low-order colors of weak double refraction. Optical anomalies observed in some sections are doubtless due to strain induced by shearing movements in the rock.

ELF GABBRO.

One specimen (C12) collected with the amphibolite at the Ledford tunnel, on the western boundary of the peridotites, 1 mile southwest of Elf (fig. 1), is a plagioclase-augite rock, which, in the hand specimen, shows a mixture of almost equal amounts of fine-grained, greenish-black, and white minerals, and has a distinctly schistose structure.

Microscopic characters.—In thin section the augite is colorless and non-pleochroic, with the characteristic high mean and double refraction of the species. There are no diallage characteristics, and it is more than half altered into a yellowish green amphibole. The latter appears of uniform granular texture where the alteration is complete, and surrounding and extending into the remaining portions of the augite. The pleochroism of the amphibole is: $\mathfrak{a}$ = light yellowish green, $\mathfrak{b}$ = dark yellowish green, $\mathfrak{c}$ = green. Absorption: $\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$. In all other respects the rock is identical with the feldspathic or dioritic facies of the amphibolites, described above.

The process of alteration observed here is in many respects similar to that described by Dr. G. H. Williams[3] in the gabbro-diorites in the vicinity of Baltimore, Maryland. The pyroxene in this case is less ferriferous, however, and the change takes place without the separation of large quantities of magnetite.

SHOOTING CREEK DUNITE.

Megascopic characters.—The rock varies in appearance from the typical, yellowish green and dark-green granular dunite to a dark-green, compact or schistose chlorite rock, in which no other constituents are recognizable to the unaided eye. The fresher type preponderates in the vicinity of Shooting Creek post-office; the more altered compact rock occurs abundantly on Giesky Creek, 1 to 2 miles southward.

Microscopic characters.—The granular dunite shows, under the microscope, perfectly fresh olivine with considerable development of pinacoidal cleavage. In many of the cracks and along the borders of the grains, small amounts of chlorite are developed, but no serpentine. Magnetite granules are also segregated into clusters and irregular streaks, and frequently show a skeleton arrangement (Pl. XXXV, fig. 1), surrounded by a corona of irregularly radiating chlorite. Minute three-ply veins also occur, as shown in Pl. XXXV, fig. 2, with chlorite in the middle and a layer of carbonates on each side, adjoining the fissured olivine, in which chlorite is also developed in the cracks.

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[3] Bulletin U. S. Geol. Survey, No. 28, 1886, pp. 40-49.

The darker compact rock appears under the microscope as a dunite in which one-half or more of the olivine has altered into chlorite. The olivine is greatly fissured and often shows high development of cleavage. The chlorite, developing between the grains and through the fissures, appears in felted, scaly aggregates or as an interlacing tangle of elongated lath-shaped individuals (Pl. XXXV, fig. 3). Magnetite in irregular patches and skeleton aggregates is more abundant than in the fresher rock, and carbonates are plentiful.

THUMPING CREEK HYPERSTHENITE.

On Thumping Creek, about 1 mile from its mouth and 3 miles east of Shooting Creek post-office, occur two dikes of very dark-green, fine-grained hypersthenite, associated with corundum. The rock shows many small, glistening cleavage surfaces on the fresh fracture, but none of its constituents is recognizable by the unaided eye.

Microscopic characters.—Examined in thin sections with the microscope it is found to be composed of hypersthene, one-half to three-fourths altered to hornblende. Both of the present constituents have a fairly uniform granular structure. The hypersthene is pleochroic: $\mathfrak{a}$ = brownish red, $\mathfrak{b}$ = pale yellowish red, $\mathfrak{c}$ = pale green; basal sections show the emergence of an obtuse bisectrix, and the optical character is negative. Incipient alteration of the hypersthene is shown by the occurrence of irregular grains and fine granules of magnetite scattered through many of the individuals. Similar magnetite aggregates occur more abundantly and frequently form large, ragged masses in the hornblende. A few fractured irregular grains of olivine also occur.

The secondary character of the hornblende is most clearly shown by the manner in which it penetrates some of the hypersthene grains and surrounds unaltered remnants of the latter. It has an extinction angle, $\mathfrak{c} \wedge c$, of 15° to 20°, and is pleochroic: $\mathfrak{a}$ = pale yellowish green, $\mathfrak{b}$ = yellowish green, $\mathfrak{c}$ = green; absorption $\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$.

BUCK CREEK AREA.

In many respects the area occupied by peridotites and related rocks in the vicinity of the Buck Creek corundum mines is the most remarkable in the State. As shown by the map (Pl. V), these rocks constitute an elongated mass lying east and west chiefly between Buck Creek and Little Buck Creek. The outcrop is about 1½ miles long, about three-fourths of a mile broad at its eastern extremity, and tapers westward to a point. Branching off from the southeastern corner of this mass and following approximately parallel to the eastern and northern boundaries, at a variable distance from the parent mass, is a narrow strip of peridotites and other rocks with which they are intimately associated. This apophysis varies from about 400 feet wide on the east to almost nothing along a considerable portion of the northern boundary. The greater part of the area is occupied by peridotites, and of these the dunite is by far the most important.

BUCK CREEK DUNITE.

Megascopic characters.—The dunite in the unaltered portions is light yellowish green to dark oil-green in color and of medium- to fine-grained texture. It frequently possesses a laminated structure similar to that of the Webster dunite, though this character is by no means constant. In the various stages of serpentinization it becomes dark-green to greenish or brownish black. Black grains of chromite can generally be seen in the hand specimen. On the weathered surfaces the dunite of this area is very similar to that of the other districts throughout the region, and presents the characteristic dark-brown or dun color, except where very much serpentinized, and in such places it is nearly black.

Microscopic characters.—The rock consists essentially of olivine with small, variable amounts of green and colorless amphibole, chromite, and magnetite. In a great majority of the sections studied, alteration has given rise to one or more of the secondary products—serpentine, talc, chlorite, carbonates, and iron oxides.

The olivine is perfectly colorless in the thin section and never shows crystal boundaries. It is generally cracked irregularly, particularly in the beginning of the change to serpentine. It also frequently exhibits well-developed parallel cracks representing the brachypinacoidal cleavage, and sometimes distinct basal cleavage, as well. In basal section, cleavage parallel to the macropinacoid can often be seen also. The grains usually average from 0.5 mm. to 1 mm. in diameter, though isolated individuals of 5 mm. to 6 mm. are sometimes seen. With the exception of occasional rounded grains of chromite, the olivine is entirely free from primary inclusions. In polarized light the olivine grains occasionally exhibit two or three narrow twining lamellæ.

With the beginning of alteration the borders and portions along the cracks often become clouded with dust-like or granular segregations of iron oxides, which impart a color to these bands varying from light-brown to almost black, according to the amount and constitution of the oxides. Frequently irregular, ragged-looking grains and skeletons of these oxides, almost as large as the olivine grains, are formed at intervals through the rock and are almost invariably associated with lath-shaped or confused aggregates of chlorite (Pl. XXXVI, figs. 2, 3).

The alteration of the olivine proceeds, in general, in the usual manner, that is, serpentine is formed at the peripheries and along the irregular cracks first, inclosing and gradually replacing the olivine; but frequently serpentine or chlorite is first formed along the planes of the basal cleavage, even when this is much less perfectly developed than the pinacoidal (Pl. XXXV, fig. 4). The usual alteration gives rise to serpentine with black or brown oxides and a little chlorite. The bulk of the oxides is usually segregated during the early stages of alteration and accumulates along the original boundaries of the olivine grains, thus frequently distinctly marking their extent in the resulting serpentine, unless disarranged by subsequent dynamic disturbances. Pl. XXXV, figs. 4 to 6, illustrate the normal process of serpentinization. Pl. XXXVI, fig. 1, shows the same process accompanied by shearing movements that have produced lamination in the rock.

In some cases the olivine alters extensively to chlorite, which penetrates the grains generally along the cleavage cracks first, though frequently in diagonal directions, in long slender laths, sometimes passing uninterruptedly through two or three grains. In the early stages of alteration the effect of pressure due to the increasing bulk is often seen in the wavy extinction of the olivine.

The amphibole is frequently present in small clusters or scattered individuals, somewhat elongated parallel to the vertical axis, frequently with prismatic development, but never having terminal planes. It is pale-green in color with very weak pleochroism and absorption, often scarcely perceptible. A colorless variety, also met with occasionally, in much longer laths with frequent cross-fracturing, is considered to be cummingtonite. (See footnote, p. 67.)

The chromite and magnetite sometimes occur in distinct octahedrons, though they are usually rounded and irregular in shape. The chromite varies from opaque, which is the usual condition in this locality, to brownish translucent. By reflected light the chromite is dull, and is thus distinguished from magnetite, which has a bluish, metallic luster. With the slightest beginning of alteration in the rock, these constituents are found surrounded by chlorite arranged perpendicularly to the boundaries or in confused aggregates (Pl. XXXVI, fig. 2). The skeletons and ragged aggregates of magnetite frequently seen are considered secondary, as noted above.

In one section (B23) the yellowish brown translucent grains are bordered by narrow strips of opaque material, which by reflected light is dull-brownish in color. These opaque borders also penetrate irregularly into the translucent portions, sometimes replacing them altogether (Pl. XXXVI, fig. 4). Such masses are invariably surrounded by the halo of chlorite, which characterizes the chromite of most of the sections from this locality. These phenomena seem to indicate that translucent chromite has altered to opaque material, possibly through the loss of alumina in the formation of the surrounding chlorite.

Analysis of Buck Creek dunite.

[By Dr. Charles Baskerville, University of North Carolina.]

SiO_2	38.52
TiO_2	none
Al_2O_3	1.60
FeO	11.24
MnO	.28
CaO	1.23
MgO	37.55
Na_2O	3.61
K_2O	2.37
Loss on ignition	3.30
	99.70

BUCK CREEK AMPHIBOLE-PERIDOTITE.

By an increase in the proportion of the light-green amphibole, dunite passes into the amphibole-peridotite. This occurs on top of the mountain near the center of the Buck Creek area (Pl. V) and at the pointed western extremity of the outcrop. In these places considerable bodies of the rock are found; smaller masses are encountered in the apophysis to the east and north of the main mass.

Megascopic characters.—In general aspect the amphibole-peridotite is considerably darker than the dunite, being dark grayish green to greenish black in color. The granular vitreous olivine and the small glistening cleavage faces of the amphibole can usually be seen distinctly in the hand specimen. The altered portions bear large amounts of chlorite, which appear in the form of small greenish scales.

Microscopic characters.—Microscopically the fresh rock is identical with the dunite described above, except for the presence of a large amount of pale-green amphibole. In the process of alteration the olivine gives rise to both serpentine and chlorite, and the amphibole alters entirely to chlorite. The chlorite usually appears in the form of much elongated lath-shaped strips without any discernible orientation with reference to the parent mineral. In some cases, the alteration of both constituents produces chlorite with dark streaks and patches of rejected iron oxides (Pl. XXXVI, fig. 5). Both constituents are shown in Pl. XXXVI, fig.

6, and the chromite is typically surrounded by chlorite, although the rock is only slightly altered. An olivine from this rock exhibiting twin lamellæ is shown in Pl. XXXVII, fig. 1.

In some partially altered sections the amphiboles are clouded in the interior with minute dust-like specks, which are elongated and frequently arranged in lines parallel to the vertical axis of the amphibole. With high powers these are seen to be yellowish brown, translucent, and are supposed to be the iron oxides differentiated in the incipient stages of alteration. The individuals that exhibit this phenomenon are clear and colorless in a narrow strip around the border (Pl. XXXVII, figs. 3, 4).

Analysis of Buck Creek Amphibole-peridotite.

[By Dr. Charles Baskerville, University of North Carolina.]

SiO_2	44.61
TiO_2	Trace
Al_2O_3	14.28
FeO	14.59
MnO	Trace
CaO	2.56
MgO	15.68
Na_2O	0.97
K_2O	0.27
Loss on ignition	7.17
	100.13

BUCK CREEK TROCTOLITE AND OLIVINE-GABBRO.

Two small areas in the narrow eastern strip of peridotite at Buck Creek, and a much smaller one on top of the mountain at the extreme southern border (see map Pl. V) are composed of highly feldspathic facies of the rock that may properly be called troctolite. By the accession of augite, portions of these masses pass into olivine-gabbro. Altogether they comprise an area of somewhat less than 10 acres. A similar rock occurs in the southern part of the Elf peridotite, on Shooting Creek, Clay County, and another is found 1 mile north of Young-Harris on Brasstown Creek, Towns County, Georgia (p. 68).

Megascopic characters.—On fresh fracture the rock is seen to be composed of oil-green to yellowish green olivine, mottled and speckled with patches and rounded areas of bluish gray, translucent to white opaque plagioclase. Occasionally plates of augite also occur. Separating the plagioclase from the olivine, there is nearly always distinctly visible to the naked eye on a fresh fracture a dark-green band, often attaining a width of a millimeter. The proportion of plagioclase to olivine is extremely variable; the olivine, however, usually predominates. Black grains of chromite and occasional grains and clusters of pyrite are also observed.

On the weathered surface the color is generally the dull dark brown, characteristic of the peridotites; but the surface is made exceedingly rough and knotty by the projecting feldspars with their green sheaths (A of Pl. XIII). In fact, the feldspars thus protected are so much more resistant than the olivine that they weather out in considerable numbers and accumulate about the exposed ledges of the rock.

Microscopic characters.—In the thin section the rock is found to consist of rounded granular olivine, broad cleavable feldspars, and between these constituents the green mantle that is noticeable in the hand specimen is found to consist of parallel or concentric layers of fibrous and reed-like aggregates, set approximately at right angles to the boundaries of the adjacent minerals. A number of sections from the olivine-gabbro facies also contain broad, irregular, augite areas, sometimes poikilitic, inclosing olivine and feldspar grains, and generally more or less altered to uralitic amphibole. In addition there are occasional grains of yellowish brown translucent chromite, or picotite, sometimes in considerable abundance.

The olivine is in rounded or irregular angular grains of the same character as that of the peridotites proper, sometimes perfectly fresh, sometimes considerably altered along the cracks to yellowish or greenish serpentine. It often includes small grains of the chromite or picotite.

The feldspar occurs in broad rounded masses, often 5 to 10 millimeters in diameter. Polysynthetic twinning is almost universal, the sections often presenting two sets of lamellæ, corresponding to the albite and pericline laws. Two sets of cleavage cracks are also well developed, and the angles of extinction with these range as high as 35 to 40 degrees. The mineral is completely decomposed in boiling dilute hydrochloric acid, with the separation of abundant gelatinous silica. The following partial analyses prove the mineral to be typical anorthite.

Analyses of anorthite from Buck Creek troctolite.

[I, by J. Volney Lewis; II, by J. E. Mills, University of North Carolina.]

	I.	II.
SiO_2	44.45	44.72
Al_2O_3	36.75	35.86
Fe_2O_3	Trace	Trace
CaO	18.44	Undet.
H_2O (ign.)	0.52	Undet.
	100.16	80.54
Specific gravity	2.798	....

As a rule the feldspar is remarkably well preserved, showing scarcely more than a trace of kaolinization. In portions bordering upon the olivine, however, and sometimes throughout the mass, it presents a dusty, clouded appearance under low powers, which with higher magnification is resolved into great numbers of rounded and elongated pale-greenish inclusions. In some portions these merge into large, ragged masses of considerable size, darker green in color and isotropic, and are considered to be a green spinel, probably pleonaste. In several sections this is quite abundant.

A peculiar alteration of the anorthite into chlorite is shown by the manner in which the latter penetrates the grains, both in elongated laths and fine, scaly, felted aggregates (Pl. XXXVII, figs. 5, 6).

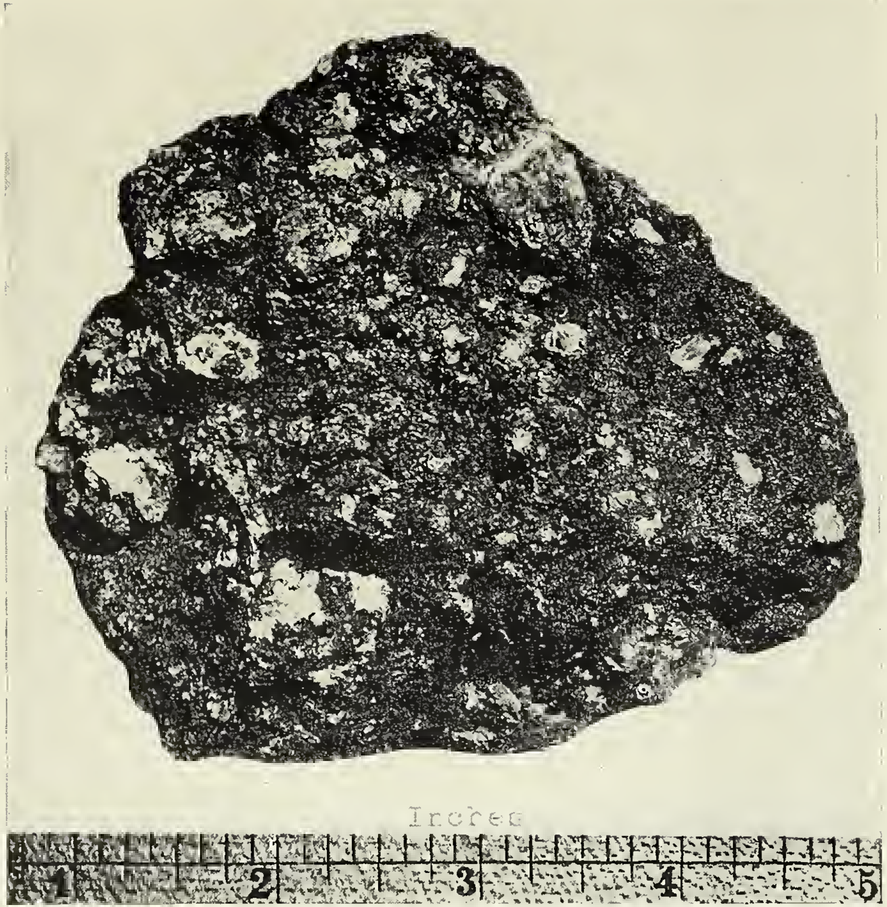
The picotite, or chromite, occurs in considerable abundance and has the same general characters as in the other olivine rocks. It is of varying degrees of translucence, and is bright yellowish brown to dark brown in color, the dark-colored grains being nearly opaque. It is frequently included by the olivine and occasionally by the feldspars; though in the latter case it is never in direct contact with the feldspar, but is separated by a mantle, sometimes very thin, resembling portions of the mantle between the olivine and feldspar. The optical properties of this mantle, so far as determinable, are those of amphibole. Occasional grains of spinel show a honey-yellow central area like picotite and gradually pass into light green toward the borders, where it resembles pleonaste (Pl. XXXVII, fig. 2).

The augite occurs in large, irregular plates, and often encloses poikilitically numerous grains of feldspar. It is colorless to pale green and dusty brown, the latter color doubtless representing the initial stages of alteration whereby minute particles of iron oxides are differentiated. It has well-developed prismatic cleavage, but no diallage characteristics. It presents every stage of alteration to pale-green amphibole in slender fibers arranged approximately parallel to the vertical axis. In this process considerable separation of iron oxide often takes place, and these accumulate more or less along the cleavage cracks of the augite and between the fibers of the secondary amphibole (Pl. XXXIX, fig. 1).

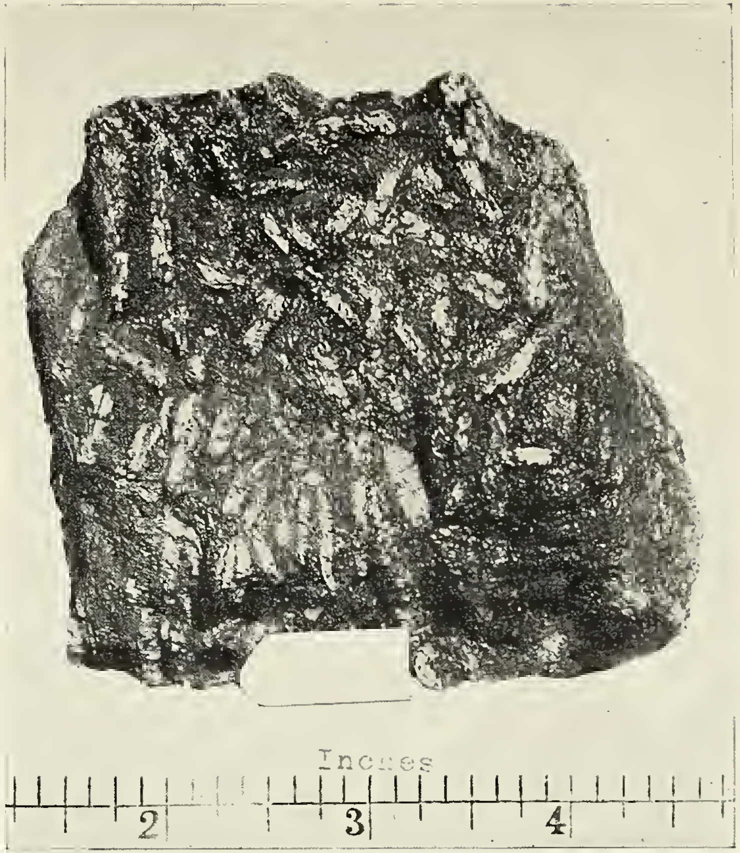
Analysis of Buck Creek troctolite.

[By Dr. Charles Baskerville, University of North Carolina.]

SiO_2	38.72
TiO_2	Trace
Al_2O_3	16.06
FeO	11.24
MnO	.24



A, TROCTOLITE, SHOWING KNOTTED WEATHERED SURFACE ABOVE, FROM BUCK CREEK, CLAY COUNTY.



B, CORUNDUM IN AMPHIBOLITE, BUCK CREEK, CLAY COUNTY.

CaO	5.37
MgO	19.01
Na_2O	5.25
K_2O	.34
Loss on ignition	3.16
	99.39

CORROSION MANTLES IN TROCTOLITES.[4]

The sheaths or mantles separating the olivine from the feldspar in these rocks are probably thicker and their constituent minerals more distinctly developed than in any similar occurrences thus far described, thus permitting a more satisfactory determination of these interesting aggregates than has heretofore been found possible. Their principal characteristics and variations are shown in the photomicrographs reproduced in figs. 1-6, Pl. XXXVIII. They are found to vary from the minutest dimensions to more than a millimeter in thickness, and are frequently prominent in the hand specimen. They are typically two-ply or three-ply in character, rarely composed of a single layer: The layers of different composition are arranged parallel or more or less concentrically according to the form of the olivine-feldspar surfaces upon which they are developed. The middle layer is usually thinnest, and the one next the feldspar thickest, appearing in the section as a broad belt.

Enstatite layer.—The portion next to the olivine consists of short, rather stout parallel or radial stalks or columns of a colorless mineral. They exhibit moderate mean refraction and rather strong interference colors, with extinction parallel to their greatest elongation. This direction is also that of the axis c (least elasticity). Large developments of this portion in section B56 have produced masses with parallel cleavage cracks and the optical properties of *enstatite*. Occasionally the other layers thin out altogether, leaving only this one between the olivine and the feldspar; and, although somewhat variable in thickness, this layer is always present.

Diopside layer.—The middle part can scarcely be distinguished in natural light from the one just described. It is made up of short columnar individuals approximately normal to the bounding surface of the olivine and feldspar. It is sometimes apparently continuous with the adjacent enstatite, or intergrown with it and, like it, colorless and possessing a high index of mean refraction. Its very strong double refraction and large extinction angles $c \wedge c$, which range as high as 36°, sharply differentiate this middle layer from the enstatite. The properties are identical with those of *diopside*. This is the least constant portion of the mantle, thinning out and coming in irregularly and often almost entirely wanting.

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[4] The terms "rim," "zone," and "belt," which have been generally applied to these aggregates, are somewhat misleading in that they express but two dimensions, whereas the phenomena described are prominently developed in three. The prevailing confusion in this respect is well exemplified in Rosenbusch's Mikroskopische Physiographie, where "Zone," "Gürtel," and "Rand" are used indiscriminately and interchangeably with "Schale," "Rinde," "Mantel" and "Umhüllung." Manifestly the words of the former group are used with reference to the appearance in the thin section, where usually but two dimensions are observed, while those of the latter group conform more closely to the actual conditions. *Mantle* seems to be, upon the whole, the least objectionable term, and *corrosion* expresses their probable origin better than "reaction;" hence the term *corrosion mantles* adopted here.

Actinolite layer.—The layer next the feldspar is often thicker than both of the others together. Though it sometimes thins down considerably, and even disappears occasionally, it is seldom absent altogether, and never for any considerable space. In the section it appears pale greenish in color and is composed of fine fibers set in the same general manner as the thicker individuals of the other layers. The fibers, however, are often radial or gathered into a succession of sheaf-like bundles. They exhibit a moderately high mean refraction, and their double refraction is somewhat weaker than that of the diopside but much stronger than that of the enstatite. The c-axis makes an angle of about 16° with the fibers. These properties identify this mineral as *actinolite.*

A very thin portion of this actinolitic layer, appearing in the section as a narrow strip next the augite or enstatite, is usually clear and free from inclusions, while the rest of it, by far the greater part, is thickly crowded with darker green isotropic inclusions in parallel fibers and confused vermiform and ragged masses. These are often continuous with the similar fibers and isotropic masses in the feldspars, described above, and are doubtless *pleonaste.*

The ends of the fibers of actinolite next the feldspar sometimes give the appearance in polarized light of another layer to the mantle. These are, however, simply the extremities of the actinolite fibers which have been altered into pseudomorphous chlorite (Pl. XXXVIII, fig. 6).

These mantles may be closely compared with the "reaction-rims," "corrosion-zones," etc.. that have been frequently observed in similar relationships in olivine-gabbros, olivine-norites and feldspathic peridotites. The first published description was by Dr. A. E. Törnebohm[5] in 1877, from an occurrence of hyperite in Sweden. The mantle is double, consisting of tremolite next the olivine and of actinolite next the feldspar.

Dr. F. Becke[6] describes similar phenomena from the olivine-gabbros of Lower Austria, the mantles being three-ply. The innermost layer

[5] Neues Jahrbuch, 1877, pp. 267-283.

[6] Tschermak's Min. und Petr. Mitth., Vol. IV, 1882, pp. 322-352.

(next the olivine) is fibrous, colorless tremolite; the middle one is a brownish, highly refracting, finely fibrous mineral that borders sharply upon the innermost layer, but is intergrown with the inner portions of the outermost one. The outermost layer, next the feldspar, is a pale-green, granular to scaly mineral with strong double refraction.

Dr. F. D. Adams[7] described in 1885 very similar "reaction-rims" from the olivine-anorthosites of the Saguenay River region of Canada, which closely resemble those of Buck Creek. The olivine is surrounded by a double mantle, the inner portion consisting of orthorhombic pyroxene, the outer and thicker part of actinolite.

Dr. G. H. Williams[8] describes "reactionary rims" between the olivine and feldspar in olivine-gabbros and feldspathic peridotites near Baltimore, Md., as follows:

> The feldspar is shown by all its physical properties to be bytownite * * * . Whenever it comes in contact with the olivine, the peculiar reactionary rims of amphibole described by Törnebohm are finely developed. The interior zone of these rims next to the olivine is narrow, granular, and almost colorless. Outside of this is a darker greenish portion, having a feathery appearance; this exterior zone projects in rounded tufts into the feldspar substance, at the expense of which it has apparently been formed.

Dr. A. E. Törnebohm[9] also described, in 1889, another occurrence in a hyperite from Sweden, which is even more like those here under consideration. The mantles are double, the layer next the olivine being of orthorhombic pyroxene, the outer of green hornblende with pleonaste.

The gabbro described by Dr. G. F. Matthew[10] in 1894, from the vicinity of St. John, New Brunswick, also exhibits very similar phenomena. The olivine is surrounded by double mantles separating it from the feldspar, the inner layer consisting of granular enstatite, the outer of radial aggregates of actinolite, intergrown in its outer portions with abundant green spinel.

Dr. H. Rosenbusch[11] mentions several other more or less similar occurrences in various parts of Europe.

The origin of these corrosion mantles is discussed in connection with the origin and relations of the peridotites, Chapter V (p. 146).

BUCK CREEK AMPHIBOLITE.

Amphibolite forms long, narrow, dike-like outcrops cutting the peridotites in several radial directions on top of the mountain, near the middle of the Buck Creek area (see Pl. V). Smaller masses follow the peridotite throughout the extent of the narrow apophysis to the east and north of the main mass. The width of the amphibolite outcrop varies from 20 to 200 feet and over, and the aggregate length of such outcrops in the Buck Creek area is more than 5 miles.

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[7] Am. Naturalist, Nov., 1885, pp. 1087-1090.

[8] Bulletin U. S. Geol. Survey No. 28, 1886, p. 52.

[9] Geol. Fören. i Stockholm Förh., Vol. XI, 1889, p. 46.

[10] Trans. N. Y. Acad. Sci., Vol. XIII, 1894, p. 185.

[11] Mikroskopische Physiographie, 3d ed., 1896, pp. 314-316.

Megascopic characters.—The amphibolites appear as light-green, and emerald- to dark-green, fine-grained rocks, generally distinctly gneissoid in structure, and often bearing considerable pink to ruby-red corundum in irregular cleavable masses. The amphibole is usually the prominent constituent, and frequently there is no feldspar present at all. But in this respect the rock is exceedingly variable, feldspar often becoming predominant locally, even sometimes to the exclusion of the amphibole, giving rise to anorthosite facies. These variations occur within very short distances, the extreme types being sometimes found in a continuous mass within a few feet of each other. When strongly banded, alternate laminæ a few inches in thickness, often present strong contrasts of green and white, according as amphibole or feldspar predominates. Locally it is frequently sheared and altered more or less completely into chlorite-schist.

Microscopic characters.—In thin sections the chief constituents are usually pale-green to grass-green amphibole, plagioclase (generally in small amount but large individuals), more or less brown translucent picotite, and often corundum. Less frequently green spinel and augite are present. Not one of the constituents is found, however, in all the sections. Most of them contain amphibole abundantly, with more or less plagioclase; some contain only these two minerals. Other combinations are amphibole and corundum; amphibole and picotite; amphibole, picotite, and green spinel; amphibole, picotite, and corundum; plagioclase, picotite, and corundum; amphibole, plagioclase, picotite, and corundum; amphibole, plagioclase, and augite.

The amphibole is usually of moderately fine grain, somewhat elongated parallel to the prevalent gneissic structure; but it varies from fine fibers in confused felted masses (Pl. XXXIX, fig. 2), or approximately parallel uralitic aggregates to uniform, medium sized grains, comparable in size with the plagioclase. Numerous basal sections exhibit the combination of prism and clinopinacoid, but frequently such sections are irregular in outline. Minute amphibole laths enclosed in the feldspar of section B71 sometimes exhibit terminal planes. Extinction angles, $c \wedge c$, varying from 18 to 24 degrees were observed. The amphibole is often pale green and non-pleochroic; but frequently it encloses small grains and dust-like particles of picotite, or is associated with larger masses of this mineral, and is then bright grass-green to emerald-green in color, and is distinctly, though not strongly, pleochroic (B4, B69, B12): $\mathfrak{a} =$ light bluish green; $\mathfrak{b} =$ light yellowish green; $\mathfrak{c} =$ sky-blue. Absorption $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$.

In section B36, from near the main shaft east of the creek, the amphibole is filled, except in a narrow clear border, with rounded, drop-like, rod-like, and fibrous vermiculate masses of green spinel (Pl. XXXIX, fig. 3). The inclusions are much like the green spinel in the corrosion mantles of troctolite, and are readily identified by their frequently coalescing into ragged masses of considerable size.

In several sections from the narrow belt to the east and north of the main mass (B54, B70, B71) the amphibole is highly uralitic, and derived, in part at least, from augite, which is still represented by scattered remnants. Plate XXXIX, fig. 4, shows a basal section of augite partly changed into amphibole. Some of the augite occurs in large poikilitic masses, enclosing grains of feldspar, and comparable in every way with the augites of some of the troctolite sections.

The analyses of the amphibole from this rock show it to be an aluminous variety, poor in iron. Dr. J. D. Dana classed it with *edenite,* but Dr. F. A. Genth,[12] who first described the mineral, called it "*smaragdite* (?); *kokscharowite.*" On account of the prevalent bright green color of this amphibole, Dr. Genth's suggestion of smaragdite has been accepted by a number of writers, in spite of the fact that the mineral is highly aluminous.

A more recent analysis of this mineral, by Dr. Charles Baskerville, of the University of North Carolina, is given in No. I of the table below. The mineral was separated from a banded specimen of amphibolite collected on top of the mountain near the center of the peridotite area. The crushed material retained between sieves of 72 and 112 meshes to the inch was separated with Thoulet's solution. The emerald-green grains sank in solution of specific gravity 3.085. Under the microscope, these all showed picotite inclusions. The lighter green portions, which were found to be entirely free from picotite, were suspended in the solution at specific gravity of 3.075. This material was used for analysis I. The analysis of the mineral described by Dr. Genth is given in column II of the table below. He describes it as having "a bright color between emerald- and grass-green, gradually passing into grayish green and greenish gray. Specific gravity of the grass-green variety, 3.120."

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[12] Bulletin U. S. Geol. Survey No. 74, 1891, p. 45.

Analyses of edenite from the amphibolite of Buck Creek, Clay County.

[I, by Chas. Baskerville; II, by F. A. Genth.]

	I.	II.
SiO_2	44.38	45.14
Al_2O_3	17.32	17.59
Cr_2O_3	0.38	0.79
FeO	3.83	3.45
NiO	....	0.21
MgO	15.48	16.69
MnO	0.90	....
CaO	11.51	12.51
Na_2O	1.24	2.25
K_2O	0.38	0.36
H_2O	4.63	1.34
	100.05	100.33
Specific gravity	3.075	3.120

The plagioclase of the amphibolites is anorthite. It is very variable in amount and is sometimes entirely wanting. It occurs in large, somewhat rounded, irregular grains, and thus often presents a striking contrast with the fine-grained or even fibrous amphibole (Pl. XXXIX, fig. 2), although sometimes the two constituents are almost of uniform texture. Multiple twinning is almost universal, often according to both the albite and pericline laws. The anorthite sometimes encloses small laths of amphibole and small grains and specks of green spinel. Some clouding is generally noticeable, but only seldom has kaolinization reached an advanced stage. Clear, fresh grains separated from the crushed rock by Thoulet's solution, as described above for the amphibole, were held in suspension at a specific gravity of 2.753. On examination with polarized light these grains gave extinction angles with the cleavage ranging chiefly between 32° and 37°. The inclination of the rhombic section to the basal cleavage, in a large number of measurements, ranges from 17° 55′ to 18° 40′.

The mineral decomposes readily in boiling dilute hydrochloric acid, with the separation of abundant gelatinous silica. The following partial analyses agree with the optical characters in determining it unmistakably as anorthite.

Partial analyses of anorthite from amphibolite of Buck Creek, Clay County.

[I, by Dr. Charles Baskerville, University of North Carolina; II, by J. Volney Lewis.]

	I.[13]	II.
SiO_2	40.40	41.74
Al_2O_3	36.40	36.69
CaO	18.72	20.14
H_2O (ignition)	....	0.25
	95.52	98.82
Specific gravity	2.744	2.753

Corundum occurs frequently in small rounded grains intergrown with picotite (Pl. XXXIX, fig. 5), and in such cases is always distinctly colored and pleochroic, light yellowish green and purple. It is also frequently present without intergrown picotite in light pink to colorless grains of various sizes, the larger ones having well developed rhombohedral parting (Pl. XXXIX, fig. 6). Some portions of the amphibolite contain corundum in fragments of considerable size as is illustrated in B, Plate XIII.

The augite that is found in a few of the amphibolite sections has the same characteristics as in the troctolites. It is colorless to pale green and dusty brown, the latter probably due to the differentiation of iron oxide dust in the incipient stages of alteration. The augite is large and irregular in outline and is often poikilitic, enclosing grains of feldspar, The prismatic cleavage is highly developed. It presents every degree of alteration to pale-green amphibole, which is usually in slender fibers approximately parallel to the vertical axis of the augite. The black oxides are eventually segregated along the cleavage cracks of the augite and between the fibers of the amphibole.

Following is the analysis of the amphibolite from near the top of the mountain, west of Buck Creek.

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[13] Analysis I was published in Bulletin No. 11 of this Survey, page 24, where the lime and alumina percentages were accidentally interchanged; it was also erroneously placed under troctolite instead of amphibolite.

Analysis of Buck Creek amphibolite.

[By Dr. Chas. Baskerville, University of North Carolina.]

SiO_2	37.86
TiO_2	.03
Al_2O_3	24.64
FeO	6.37
MnO	0.20
CaO	15.25
MgO	8.45
Na_2O	1.55
K_2O	1.20
Loss on ignition	3.75
	99.30

CORUNDUM HILL AREA.

North of Cullasagee River in Macon County, the massive spur of the Cowee Mountains lying between Ellijay and Walnut creeks contains numerous outcrops of typical oval masses of dunite, of which the well-known Corundum Hill outcrop may be taken as an example (map, Pl. VI). Many of the masses are somewhat larger and different in shape from this, but the variation is nowhere very great, and in general characters the Corundum Hill outcrop is typical of the area. It is a somewhat irregular oval mass about 10 acres in extent, and the rock is exposed over almost the entire surface. The amount of enstatolite (enstatite rock), which is rather largely developed at the south end of this outcrop, is extremely variable, greatly predominating in some of the masses and scarcely appearing at all in others.

CORUNDUM HILL DUNITE.

Megascopic characters.—On exposed surfaces this rock presents the usual yellowish and reddish brown colors, and only a very thin red ocherous soil results from its complete decomposition. This being exceedingly infertile, is washed off about as fast as formed, and hence the barren and rugged character of most of the outcrops.

The fresh rock is of various shades of yellowish green, according to physical and chemical conditions. Where exposed to the weather a very slight amount of alteration increases the yellow color; a little serpentinization, on the other hand, often intensifies the green, producing a much darker looking rock. Toward the north end of the outcrop small portions of the rock are very fine grained and ash-gray in color. Thin lamination is sometimes developed, presenting alternations of light gray and dark green.

Olivine is the only abundant constituent of the rock, varying in texture from very fine to medium coarse, with occasional individuals measuring half an inch or more in diameter. Black grains and crystals of chromite are always present, and generally some plates of enstatite. Small glistening flecks of talc and chlorite, and fine slender needles of anthophyllite and cummingtonite constitute the remaining visible constituents.

Microscopic characters.—The olivine greatly exceeds all other minerals in abundance. It presents all degrees of alteration to serpentine, only in rare cases appearing perfectly fresh. It is also rarely the case that more than half of the mineral has been altered. Typical sections are shown in Pl. XL, figs. 1 to 4. The serpentine is usually light yellow or yellowish green in color, occasionally decidedly green.

The olivine in the unaltered sections, and usually also in the remnants occurring in the highly serpentinized portions, is perfectly transparent and colorless. In this locality the olivines are, so far as observed, invariably anhedrons, varying in size from .05 mm. to 12.0 mm. in diameter. The largest individuals have not been found in the coarser portions of the rock, as might have been expected, but in the very fine grained gray masses from the workings at the north end. The broken and granulated condition of the borders of such an individual (Pl. XL, fig. 1) make it not improbable that much of the now finely granulated portions has been derived from mechanical crushing of coarser material. The same figure illustrates the tendency to serpentinization along the basal cleavage first, although the pinacoidal is more highly developed.

Sections of the laminated portions of the rock show that this structure is due to fine granulation along numerous parallel shearing planes. The alteration to serpentine is also often much more pronounced along these planes (Pl. XL, figs. 3, 4).

The enstatite, which is found in most of the sections, occurs in nearly square or somewhat elongated sections of the prism zone, with well-developed vertical cleavage cracks and frequent irregular cross fractures. It is perfectly colorless and non-pleochroic, and is usually somewhat larger than the olivine grains. In the great majority of cases it is also perfectly fresh, but in some sections it is partially or wholly altered into cleavable talc plates and bastite.

The chromite occurs in sections of octahedral crystals and irregular grains, usually about the size of the associated olivine grains, though in this respect quite variable. In many cases it is wholly or partially surrounded by chlorite plates. The grains are not attracted by a horseshoe magnet. On being crushed to fine powder the smaller fragments are translucent and pale yellowish brown on the thinnest edges to dark reddish brown and almost opaque in the thicker portions. In the sections it is usually opaque and dull grayish by reflected light. Black granular secretions about the chromite or in separate clusters in the more altered portions of the rock are more metallic by reflected light, and are doubtless secondary magnetite. These sometimes build up skeleton forms.

The slender, glistening needles, often noticeable in the hand specimen, are sometimes very abundant. Under the microscope they appear as very long, slender individuals or in bundles, frequently more or less radiating (Pl. XL, fig. 2). They exhibit high mean refraction and very high double refraction. Basal sections show the typical prismatic cleavage of the amphiboles, and occasionally prismatic outlines. Longitudinal sections usually have vertical cleavage cracks partially developed, and always exhibit strong transverse fractures. Some of these show an inclined extinction of 15° to 20° or more with the vertical axis, this direction being the axis of least elasticity, while that of intermediate value coincides with *b*. These characters agree with those of tremolite, but in view of the almost entire absence of calcium from the rocks, the close similarity to the Sapphire occurrence (p. 102) and the intimate association in adjacent portions of the same outcrop with the anthophyllite described below, it is most probable that the mineral is cummingtonite (amphibole-anthophyllite).

In other sections (CH2 especially) the long needle-like crystals have exactly the same appearance in the hand specimen and in natural light under the microscope; but in polarized light they are found to extinguish always parallel to the crystallographic axes, with the greatest and least axes of elasticity parallel to *a* and *c* respectively. The basal sections afford no distinct interference figures in convergent light, owing in part at least to the fact that most of them have suffered slight mechanical deformation which gives rise to wavy and imperfect extinction. Portions of the hand specimen corresponding to CH2, and containing great numbers of these needles, showed no trace of calcium with the ammonium oxalate test. The mineral is therefore considered to be anthophyllite.

Analyses of dunite from Corundum Hill.

[By T. M. Chatard, Bull. U. S. Geol. Survey No. 42, 1887, p. 55.]

	I.	II.
SiO_2	40.11	41.58
Al_2O_3	0.88	0.14
Fe_2O_3	1.20	....
FeO	6.09	7.49
MgO	48.58	49.28
CaO	....	0.11

	I.	II.
H_2O (ignition)	2.74	1.72
Cr_2O_3	0.18	....
NiO (Tr. Co & Mn)	....	0.34
Chromite	0.56	....
	100.34	100.66

CORUNDUM HILL ENSTATOLITE (ENSTATITE ROCK).

The enstatolite (enstatite rock) of Corundum Hill differs from that of Webster in mode of occurrence, that is, in being closely associated with dunite instead of websterite. It forms large masses, especially at the lower end of the outcrop, perfectly continuous with the dunite. In the transition between the dunite and the pyroxenite, the enstatite occurs disseminated through the dunite in some cases, in others it forms veins up to 1 or 2 inches in thickness, frequently parallel and in parellel sets crossing each other at right angles. This form lends probability to the view that much if not all of the enstatite is secondary after olivine.

Megascopic characters.—In texture the rock is a coarse bladed mass, sometimes exceedingly coarse, the individuals occasionally attaining a length of 6 inches, with other dimensions half as great. It is gray to light yellowish and greenish gray, being of much lighter color than the corresponding rock at Webster. Irregular grains of chromite constitute the only other visible primary constituent. Plates and scales of talc and chlorite are also found in all specimens examined. Occasionally small portions of the enstatite are finely fibrous. The chromite grains are strongly magnetic, but give pronounced bead test for chromium. Owing to the very irregular outline of some of the grains, it seems probable that they have received accretions of magnetite granules during the alteration of portions of the enstatite. This would account for the peculiar combination of properties observed. Small, whitish, translucent grains and granular masses of magnesite are sometimes seen in the hand specimen.

Microscopic characters.—Broad, irregular areas of enstatite occupy most of the field. Basal sections show prismatic cleavage well developed and pinacoidal parting less so. Sections in the prismatic zone are very much elongated parallel to the vertical axis. The optical properties are, as a rule, normal; that is, c is the positive bisectrix, and the axial plane lies in the brachypinacoid. As occasional extinction like that of thin twinning lamellæ is observed, making a small angle with the parallel cleavage of the prismatic zone, the extinction passing like waves from one set to the other in a rotation of about 10°. The enstatite is colorless and entirely free from pleochroism. Chemical analysis is given below.

It is partially altered to bastite, which appears as parallel yellowish fibers in the cleavage cracks and along the borders, always oriented vertically with reference to the enstatite axes. In the thicker portions the bastite shows a weak pleochroism, being yellowish for rays vibrating parallel to the fibers and colorless or nearly so at right angles to them. In about the same proportions as the bastite, appears chlorite also as an alteration product of the enstatite. It occurs as thin plates, often arranged parallel to the enstatite cleavage, though frequently irregular, and in thick sections exhibiting a decided pleochroism; yellow for vibrations normal to the cleavage, green to greenish gray parallel to it.

A smaller amount of talc is also formed from the enstatite, and appears in some of the sections as elongated plates and felted scales. Large tabular masses of pale-green talc are often seen in the hand specimen. In one instance (section CH13) the enstatite is partially altered along the cleavage cracks to greenish yellow serpentine.

Chromite occurs in occasional grains in the enstatite, usually with irregular boundaries, though rectangular and triangular sections also occur. It is opaque except on the thinnest edges, which are reddish brown by transmitted light. By incident light the grains are purplish gray and have a submetallic luster.

Olivine also occurs in occasional grains in some of the sections, and is almost perfectly fresh, showing only the slightest serpentinization along some of the cracks. Its freshness and clear transparency are in striking contrast with the muddy half-altered condition of much of the enstatite.

Magnesite is distributed in frequent irregular patches through the mass of the rock. It possesses a highly developed rhombohedral cleavage but no crystal boundaries. It often contains also small irregular grains of pyrite, which are visible on close examination in the hand specimen. In one section (CH10-c) several grains of fresh olivine are completely enclosed in the magnesite.

Analyses of enstatolite (enstatite rock) from Corundum Hill, Macon County.

[I, by Dr. Charles Baskerville: II, by Frank Julian.]

	I.	II.[14]
SiO_2	51.64	57.30
Al_2O_3	0.12	Trace
FeO	9.28	7.45
MgO	31.93	34.64
CaO	0.45	....
H_2O	5.45	1.21
MnO	0.56	....
	99.43	100.60

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[14] Analysis II was published by Genth in Bulletin U. S. Geol. Survey No. 74, p. 43.

Analysis I was made on fresh-looking material, but the presence of over 5 per cent of water indicates that about 40 per cent of the rock had altered into the hydrous minerals, bastite, serpentine, talc, and chlorite. In the sections examined with the microscope, however, the secondary minerals are not so abundant.

CORUNDUM HILL HORNBLENDE-GRANITE-PORPHYRY.

A fine-grained, white, granitic dike, about 10 feet thick, and exposed for a distance of about 10 feet east and west, was found about 40 feet north of the tunnel at the south end of the peridotite. It is entirely enclosed in the peridotite and no other outcrop of the rock was found.

Megascopic characters.—The rock is of fine texture and is predominantly white, slightly speckled with dark-green hornblende. Besides this and the quartz and feldspar, which are occasionally large enough to be recognized in the hand specimen, no other constituents are distinguishable by the unaided eye. Though slightly friable on the outcrop, a microscopic examination shows the minerals perfectly fresh.

Microscopic characters.—Allotriomorphic quartz and orthoclase, with some plagioclase and occasional irregular grains of magnetite, constitute the bulk of the rock. These constituents are of uniformly fine grain, ranging mostly below 0.2 mm. in diameter. Scattered through this fine-grained mass are occasional large irregular grains of quartz and both classes of feldspars. The quartz is most abundant, is frequently fractured, and in polarized light often exhibits strain phenomena. These larger grains are about a millimeter in diameter, though the feldspars are frequently elongated beyond this dimension. The large feldspars are partially idiomorphic, though both these and the quartz grains are usually very irregular on the borders and frequently so intergrown with the fine-grained constituents of the groundmass as to suggest magmatic corrosion (Pl. XL, fig. 5). The quartz contains a few needle-like inclusions of an undetermined mineral of strong relief and high interference colors.

The hornblende occurs in porphyritic crystals and irregular grains of 1 to 2 mm., with poikilitic intergrowths of the other constituents in great abundance; in fact, the hornblende forms merely an open network binding together numerous small grains of quartz and orthoclase (Pl. XL, fig. 6). It is strongly pleochroic, as follows: $\mathfrak{a} =$ yellow; $\mathfrak{b} =$ dark green; $\mathfrak{c} =$ bluish green. Absorption $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$.

WEBSTER AREA.

WEBSTER DUNITE.

Dunite is the most important peridotite of the Webster area (Pl. VIII), forming independently the great majority of the outcrops, and usually occurring also with other varieties where these are found.

Megascopic characters.—This rock consists of an even-grained crystalline olivine, with more or less chromite disseminated through the mass in small grains and crystals. In texture the olivine varies from almost invisible grains to very coarse-grained masses, with occasional individuals an inch or more in diameter. The more common occurrences are of somewhat coarser grain than loaf sugar.

The least altered portions have a light to dark yellowish green or grayish green color, an oily to vitreous lustre, and an uneven, angular fracture. Weathering gives rise to all gradations of color from that of the fresh rock to the characteristic yellowish or reddish brown of the barren outcrops. A highly laminated structure is almost universally developed in the region about Webster (Pl. IX, A and B); and it is not unnatural that it should have been regarded as a thin-bedded olivine sandstone.[15] The lamination is parallel to that of the inclosing gneisses, and alternate laminæ frequently exhibit marked variations in color and texture.

Microscopic characters.—Transparent, colorless, allotriomorphic olivine grains constitute the mass of the rock. Chromite in scattering crystals or irregular grains is a constant accessory. Occasionally enstatite and a colorless monoclinic amphibole are present.

In the great majority of cases, even when the hand specimen looks perfectly fresh, the olivine is found to have altered somewhat to serpentine, with sometimes more or less talc, chlorite, etc. Hence the olivine grains are usually completely separated from one another by these secondary products. In many specimens, however, the alteration has been very slight; and, in a few sections, only traces of serpentine are to be found.

The olivine is transparent and colorless, and exhibits typical optical characteristics—high index of refraction, and hence considerable relief and decidedly roughened surface, very strong double refraction, giving rise to interference colors of high orders with crossed nicols. It is usually free from inclusions, though sometimes it holds small grains of chromite. It seldom has crystal outlines, and still more rarely a tendency to porphyritic development. In fresh specimens the irregular grains fit accurately into each other with no interstitial matter whatever (Pl. XLI, fig. 2). Where serpentinization has only begun, the olivine still retains its characteristic angularity; and adjoining grains, though slightly separated by secondary products, are exact counterparts in outline. It is only in a somewhat advanced stage of alteration that the corners become rounded and the section under the microscope assumes the appearance of rubble masonry.

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[15] A. A. Julien, Dunite beds of North Carolina. Proc. Nat. Hist. Soc. Boston, Vol. XXII, 1882, pp. 141-149.

In fresh specimens the olivine grains are often broken by irregular fractures (Pl. XLI, fig. 1), and occasionally exhibit imperfect cleavage parallel to the brachypinacoid (010.). With the beginning of alteration to serpentine, however, the increase in volume gives rise to stresses that greatly increase the irregular fracturing and frequently develop regular cleavage cracks in considerable numbers. In many specimens of fine texture the small grains extinguish together over considerable areas and the irregular outlines fit perfectly together. This is especially true of those massive varieties in which the alteration of the olivine is well begun. In such cases the fine texture is evidently secondary, being a mechanical result of the chemical changes (Pl. XLI, figs. 3, 4).

Where lamination is developed, as in most of the Webster outcrops, the microscope shows this to be the result of shearing, by which a large part of the olivine has been crushed into much smaller grains. The broken fragments are generally, though not always, rolled completely out of orientation, so that no indication of the original size of the grains or structure of the rock can be found in the sheared portions. The resemblance to a sandstone, which is often a striking characteristic of the outcrops, is not complete, however, in the thin section; the grains are less rounded than is usual in sandstones, and the interstitial material is the same as the larger fragments, differing only in being more finely brecciated. Alternating with the shear-zones are frequently to be found thin laminæ of typical granular dunite with the olivine grains unbroken and entirely undisturbed. Within these laminæ the grains fit perfectly together and the characters are in every respect the same as observed in the massive rock (Pl. XLI, fig. 5).

Chloritization, a mode of alteration much less common than serpentinization, is well represented in portions of the Webster dunite along the western border of the outcrop 5 miles northeast of Webster and three-fourths mile south of Addie, on the road to Hall. Thin sections of this rock show numerous small remnants of olivine, but the great mass of the rock is composed of chlorite in slender blades and radiating clusters. Small amounts of talc and carbonates are also present and numerous patches and strings of magnetite granules (Pl. XLI, fig. 6).

Chromite is a characteristic accessory in all the peridotites of the region, occurring in octahedral crystals and irregular grains disseminated through the rock. In size it is usually about the same as the olivine, though sometimes considerably larger or smaller, and is characteristically surrounded by a corona of chlorite (Pl. XLII, fig. 1). Chromite is distributed with remarkable uniformity through the dunite, the proportion varying only within narrow limits. Several grains are to be found in every thin section, constituting in most cases perhaps much less than one per cent of the bulk of the rock.

The chromite is often broken by irregular cracks containing serpentine, chlorite, or talc, but, as a rule, it is much less fractured than the olivine. In a few instances regular parting planes are well developed in two or three directions. In specimen W22 a large chromite grain was nearly all broken out in preparing the section, but the narrow rim that remains shows three equal sets of parting cracks at angles of 60° (Pl. XLII, fig. 2). Others show one or two sets of parallel fractures; but none of the sections exhibiting these phenomena possesses crystallographic boundaries, and hence it is impossible to determine the orientation. This is doubtless to be regarded as a pseudo-cleavage, or parting, due to polysynthetic twinning lamellæ parallel to the planes of the octahedron, as often observed in spinel, magnetite, franklinite, and other members of the group. This, however, seems to be the first recorded observation of its occurrence in chromite.

In several sections the chromite grains have such strongly reëntrant contours as to suggest corrosion (Pl. XLII, fig. 2). The mineral varies from a translucent yellowish or reddish brown to opaque; by incident light it varies from dull reddish brown to submetallic iron-gray. The degree of translucence depends in a large measure on the thickness of the section. The apparently opaque specimens, when examined with a high power objective, usually show some thin edge or granulated portion of the usual color and translucence. Grains from the hand specimen, that were strongly magnetic, yielded, when crushed, a reddish brown translucent powder, which gave strong reaction for chromium with sodium-ammonium phosphate. In only one instance (section W9-1) has chromite been found to contain an inclusion. The specimen was collected on the eastern border of the dunite southeast of Webster, near the river. The section shows an irregular translucent grain of chromite enclosing small grains of olivine (Pl. XLII, fig. 3). This may also be regarded as the result of corrosion of the chromite by the olivine magma, the latter afterwards crystallizing in the cavity.

Enstatite, when present, has the same characters as in the harzburgite at Balsam Gap and elsewhere; that is, it appears in broad, rounded areas, with well-developed cleavage, but without crystal boundaries. It contains numerous, pale reddish yellow interpositions which produce the *schillerization* of the hand specimen. It is often much altered to talc, serpentine, bastite, and chlorite, and particularly talc. These secondary products retain so perfectly the original characters of the enstatite that the alteration is usually not observed till the section is examined between crossed nicols.

A colorless monoclinic amphibole, probably cummingtonite, sometimes occurs in short lath-shaped crystals. In most cases this mineral is to be regarded as a secondary constituent, though it is doubtless sometimes primary. (See footnote, p. 67.)

Analyses of Webster dunite.

[By F. A. Genth, Bull. U. S. Geol. Survey No. 74, 1891, p. 47.]

	I.	II.
SiO_2	41.89	40.74
Al_2O_3	trace	trace
FeO	7.39	7.26
MgO	49.13	49.18
CaO	0.06	0.02
H_2O	0.82	0.76
NiO	0.35	0.39
Chromite	0.58	1.83
	100.22	100.18
Specific gravity	3.282	3.252

WEBSTER WEBSTERITE.

The type locality of websterite is found in the midst of the broad dunite area just southeast of the town of Webster. It forms an outcrop with a maximum width just north of the Tuckaseegee River of 550 feet, and a length of 1 mile in the direction of the lamination of the dunite, N. 10° W. The lamination here, as usually elsewhere, conforms to the direction of the axis of greatest elongation of the mass. The websterite is entirely enclosed in dunite, the western contact of the two types being distinctly visible at the locality mentioned. For a breadth of 10 feet a semblance of interlamination with dunite is found in the websterite, the alternate layers varying from a thickness of 1 foot down to less than one-fourth of an inch. The microscope shows, however, that this appearance is due to the presence of numerous shear zones in which weathering has advanced more rapidly than in the adjoining rock, causing the yellowish discoloration resembling the color of the peridotites.

Websterite occurs again 3 miles east of Webster, on Cane Creek a mile above its mouth, where it is also associated with dunite.

Megascopic characters.—Websterite is a saccharoidal aggregate of green diopside and the reddish brown bronzite variety of enstatite. It closely resembles much of the dunite with which it is associated, but has less of the prevailing yellowish tinge of that rock, is of a brighter and more decided green color, and has suffered much less alteration. Lamination, also, though not entirely wanting, is much less developed than in the dunite.

The amount of bronzite present varies considerably, but it is always in smaller quantity than the diopside, and, as noted by Dr. G. H. Williams in the original description of the rock,[16] "shows a tendency to concentrate in bands or nests." Large plates of both the pyroxenes, many times the diameter of the average grains, are frequently found throughout the mass. Sometimes these plates are chiefly diopside, sometimes bronzite, and rarely both pyroxenes are thus developed in the same section. Dr. Williams noted this condition with regard to the bronzite, and referred to it as porphyritic development. This designation is apt to be misleading, however, inasmuch as the larger pyroxenes are not phenocrysts in the usual acceptance of that term, but simply large anhedrons. Much of the rock possesses an even-grained saccharoidal texture, like the dunite.

The websterite outcrops support a moderate growth of trees, which stand out in strong contrast with the barrenness of the dunite on each side of it. This may be accounted for by the presence of lime and a little alumina in the rock, which, on decomposition, form with the ochrous products something like a normal soil.

Microscopic characters.—Under the microscope the diopside is pale green to nearly colorless, and the bronzite is light reddish brown or pale green, according to the orientation of the section. Both pyroxenes have the prismatic cleavages well developed, especially in basal sections, but seldom show more than a trace of pinacoidal parting (Pl. XLII, fig. 4). Both contain inclusions of pleonaste in small, rounded, translucent grains of green to yellowish green color. In some sections these inclusions are exceedingly numerous, varying from one to a score or more in each pyroxene grain. The pleonaste in some of the large pyroxene plates shows a marked arrangement parallel to the prismatic cleavage.

The bronzite of the Webster rock has a distinct pleochroism, rays vibrating parallel to $\mathfrak{a}$ and $\mathfrak{b}$ being light reddish yellow, and parallel to $\mathfrak{c}$, pale green. It is thus easily distinguished from the diopside, which remains pale green in all positions. In the websterite from the Cane

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[16] Amer. Geologist, Vol. VI, 1890, 44.

Creek locality, the pleochroism of the orthorhombic pyroxene is much less pronounced. The colors are pale yellowish parallel to $\mathfrak{a}$ and $\mathfrak{b}$, and very pale greenish parallel to $\mathfrak{c}$.

All of the sections have scattered grains, sometimes very numerous, of a bright grass-green diopside. Dr. Williams regarded all the monoclinic pyroxenes of this rock as chrome-diopside; but in view of the very small amount of chromium shown by the analysis of the rock, it seems much more likely that only the bright-green grains are of this variety.

Small irregular granules and dust-patches of black opaque mineral, probably magnetite, seem to indicate the beginning of alteration in a few places.

Three analyses of websterite from the Appalachian peridotite belt have been published, as given below. It will be noted that the Webster rock is richer in silica and magnesia and poorer in lime and alumina than the Maryland representatives. The Mount Diablo websterite is practically identical with that of Maryland.

Analyses of websterite.[17]

	I.	II.	III.	IV.
SiO_2	55.14	53.98	52.55	53.25
TiO_2	Trace	.15	.14	....
Al_2O_3	.66	1.32	2.71	2.80
Cr_2O_3	.25	.53	.44	.54
Fe_2O_3	3.48	1.41	1.27	.69
FeO	4.73	3.90	4.90	5.93
MnO	.03	.21	.24	.09
NiO	.11	Trace	....	.07
CaO	8.39	15.47	16.52	16.22
MgO	26.66	22.59	20.39	19.91
K_2O	Undet.	Undet.	.27	Trace
Na_2O	.30	Undet.	.27	.19
H_2O	.38	.91	1.09	.29
P_2O_5	.23	Trace	Trace	....
	100.36	100.48	100.52	99.98

I. Websterite, Webster, North Carolina; E. A. Schneider, analyst.

II and III. Websterite, Hebbeville, 6 miles west of Baltimore, Md.; T. M. Chatard, analyst.

IV. Websterite, near Bagley Creek, Mount Diablo, Cal.; W. H. Melville, analyst.

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[17] These analyses were made in the chemical laboratory of the U. S. Geological Survey. I, II, and III were published by Dr. G. H. Williams in Am. Geologist, Vol. VI, pp. 35-49. See also Bull. U. S. Geol. Survey No. 148, pp. 84, 92; and Bulletin No. 168, pp. 43, 53, 213. IV was published by Turner & Melville in Bull. Geol. Soc. Am., Vol. II, pp. 383-414.

WEBSTER ENSTATOLITE (BRONZITITE).

This rock is usually only a local facies of the websterite, forming rock masses a few feet in extent at intervals over the outcrop. In such cases it is simply an accentuation of the tendency of the bronzite, already noted in the description of the websterite, to accumulate in bunches. These enstatite masses are exceedingly resistant to weathering, and are, therefore, found weathered out on the surface as loose boulders. Such loose masses have been observed at both the Webster and the Cane Creek localities. They have also been found on the surface of the broad dunite outcrop south of Addie, and on the large, isolated lens of dunite a mile south of Cane Creek Gap. At these two localities no websterite has been found. Projecting ledges of the bronzitite were also observed *in situ* in the websterite at Webster.

Megascopic characters.—The rock is very coarse grained, dark yellowish to grayish brown in color, and glistens with numerous broad cleavage faces of vitreous to bronzy, submetallic luster. It consists almost entirely of large, interlocking plates and crystalloids of the bronzite variety of enstatite, sometimes more than an inch broad. That found with the dunite south of Cane Creek Gap is of light yellow color without distinct metalloidal luster.

Brilliant grass-green chrome-diopside, in small grains and clusters, occurs sparingly in the darker variety, and is scarcely noticeable in the hand specimen. In the lighter colored rock it is comparatively abundant, and the strong contrast in color makes it distinctly visible. It never constitutes, however, more than a very small proportion of the rock.

Microscopic characters.—In thin section, the large plates of enstatite that make up the great mass of the rock are colorless areas of large size and irregular boundaries. Most of the sections show well-developed cleavage cracks, and occasional basal sections exhibit two nearly equal sets approximately at right angles, with diagonal cracks much less perfectly developed. In no case has a distinct pleochroism been observed in the enstatite of this rock, which is rather surprising in view of the fact that it appears as a phase of the websterite, in which the orthorhombic pyroxene is invariably pleochroic.

It possesses the normal characters of enstatite, the basal sections exhibiting in convergent polarized light, the emergence of an acute bisectrix in a wide axial angle. Occasional irregular grains of chromite, and possibly magnetite, are included in the enstatite. Numerous thin microlitic plates lie in the cleavage cracks, and these are doubtless the cause of the bronzy luster so strikingly exhibited by most occurrences of the rock.

They are irregular in outline and are much elongated parallel to the vertical axis. They are translucent and light yellow to yellowish brown in color. In some of the thicker portions they are found to be isotropic, and resemble very closely the smaller chromite grains. For these reasons they are regarded as probably chromite or picotite. This view is further confirmed by the amount of alumina and chromic oxide obtained in the analysis (see p. 288). The plates are distributed irregularly through the mineral and are sometimes arranged in bands at right angles to the cleavage, the inclusions themselves lying in the cleavage planes (Pl. XLII, fig. 5). The increased development of these inclusions sometimes observed in the faulted and bent portions of the enstatite seem to indicate that they are of secondary origin. Nothing of a similar nature has been observed in the enstatite of the websterite.

Some sections of the enstatite in the vertical zone show an abnormal extinction, which has the appearance of multiple twinning at angles of 25° or less with the cleavage. In such cases the lamellæ extinguish about 10° apart, the dark bands passing gradually, like waves, from one set of lamellæ into another.

The columnar structure ("fäsrige structur" of Rosenbusch), which is often characteristic of enstatite, is found rather frequently in this rock, but not in any large proportion of the individuals. Where this structure is developed, many of the parallel columns do not extinguish at all between crossed nicols (Pl. XLII, fig. 5).

Pale-green and colorless diopside and grass-green chrome-diopside are often found in small grains about the borders of the enstatite. These have the same characters as in websterite and serve to emphasize the essential unity of the two types.

A chemical analysis and a mineralogical description of the enstatite from this rock are given on p. 288.

BALSAM GAP AREA.

As stated on p. 46, peridotites form several oval and elongated masses within 2 miles southwest of Balsam Gap, in the northeastern portion of Jackson County. The two principal masses are 1 and 2 miles west of the gap, respectively, each forming the prominent point of a small mountain ridge. The first, with a length of about one-half mile, has its principal outcrop three-fourths of a mile west of Balsam station; the second, a blunt oval mass about 800 by 1,200 feet, is cut by the railroad 1½ miles southwest of the station. Two smaller masses are also found in the vicinity. The chief constituent of all these is harzburgite, local variations in the proportion of enstatite giving rise to small masses of dunite and pyroxenite.

BALSAM HARZBURGITE.

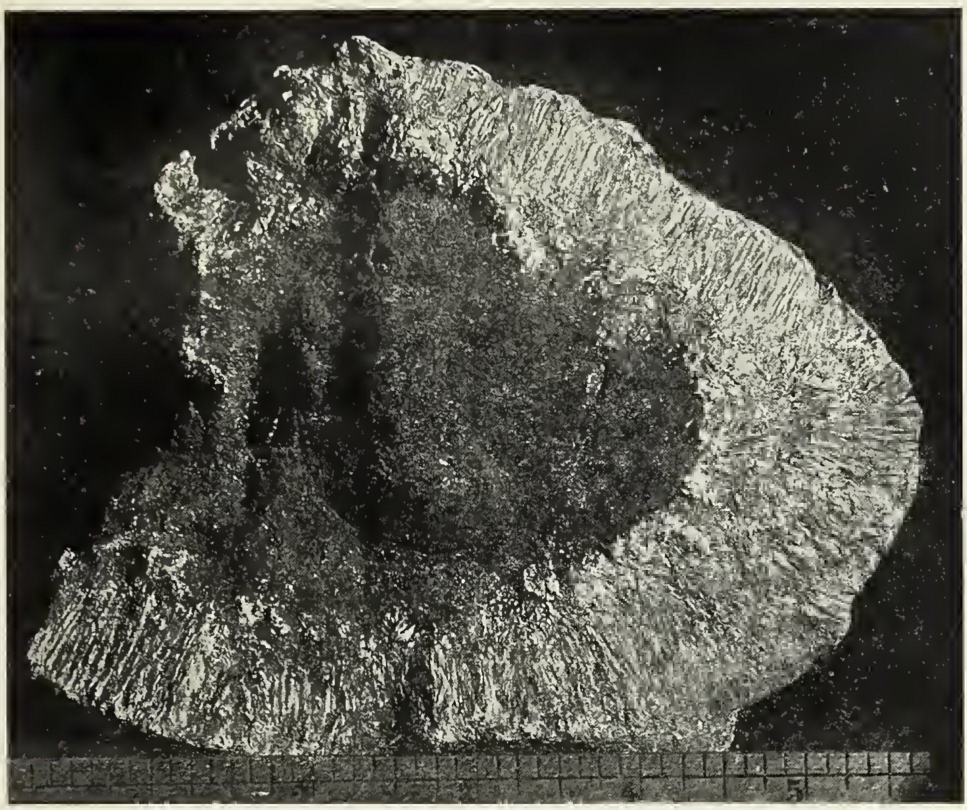
Megascopic characters.—The preceding descriptions of dunite apply to harzburgite except for the occurrence in the latter of numerous, relatively large, glistening plates of enstatite. These are usually about one-fourth inch in diameter, which is much larger than the average size of the accompanying olivine. The enstatite is yellowish white to light brown in color, with a corresponding variation in luster from pearly to bronzy metallic. On scratching it with a nail or knife point, it is frequently found to have altered completely to talc, though still retaining the characteristic appearance of the original mineral.

The enstatite is usually in more or less rounded and irregular plates, and never occurs as distinct crystals. While abundant and prominent throughout most of the outcrops of this region, it often dwindles into insignificance or disappears, forming local transitions into dunite (Pl. XLI, fig. 1).

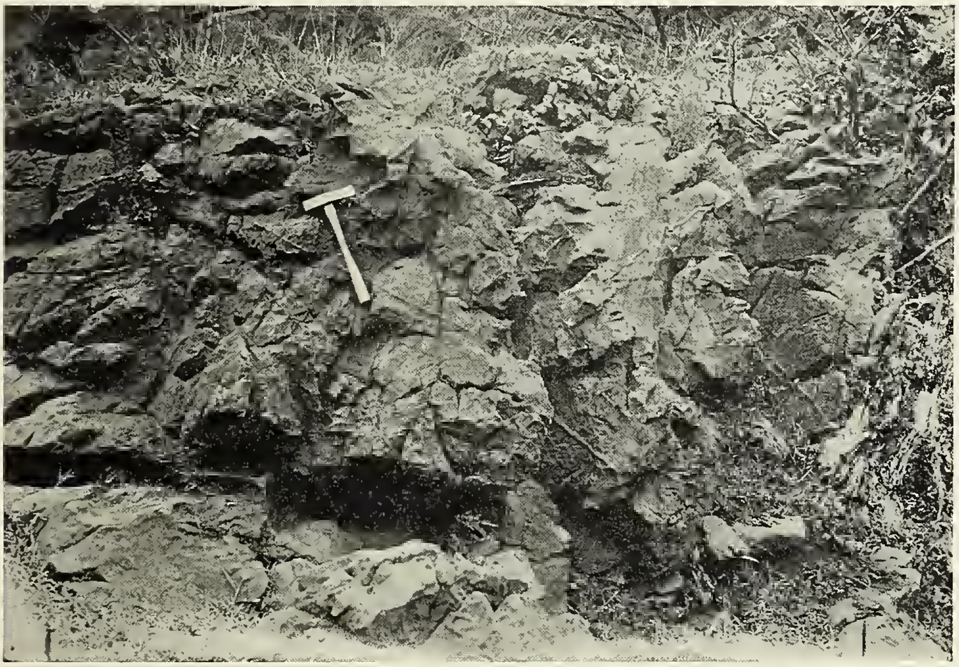
The coarse-grained character of the olivine in these peridotites is noteworthy throughout the region, and occasionally individual grains of enormous size are observed; most of them are less than one-fourth inch in diameter, though considerable numbers are more than an inch, and some individuals of 5 and 6 inches in diameter have been found. These phenomenal olivines seem to possess no other unusual characters; they are entirely irregular in shape, like the smaller grains with which they are associated, and are, in fact, simply great overgrown anhedrons.

Small prospecting pits have revealed the presence of numerous lenticular masses of granular chromite. These vary from an inch or two in thickness up to several feet. The fine-grained dunite dike, 7 inches thick, shown in Pl. X, A, cuts the harzburgite beside the railroad 2 miles west of the gap.

Microscopic characters.—The appearance of the rock under the microscope is exactly the same as dunite, except for the occurrence of large irregular enstatite areas. These almost invariably contain the yellowish red interpositions that produce the *schiller* observed in the hand specimen. The enstatite exhibits well-developed cleavage but no crystal boundaries. It is frequently much altered to talc, chlorite, and bastite, in varying proportions, though this does not usually appear, except when examined between crossed nicols. In natural light, the secondary products retain all the characters of the enstatite, including the characteristic interpositions, just as, in the hand specimen, it seems to be perfectly fresh until its softness is discovered by scratching.



A, DUNITE NODULE (DECOMPOSED) ENCLOSED BY RADIAL SHEATHING OF TALC, AFTER ENSTATITE, HICKORY KNOLL CREEK, MACON COUNTY, N. C.



B, WEATHERED SURFACE OF DUNITE EXPOSED NEAR WEBSTER, JACKSON COUNTY, N. C.

SAPPHIRE AREA.

DUNITE AT THE BAD CREEK MINE.

The outcrops of the lenticular mass at this place (see Pl. VII) are composed chiefly of enstatolite, made up of gray interlocking blades of enstatite. By the introduction of olivine it passes in places into harzburgite, and by the elimination of the enstatite, into dunite. Only the dunite facies was studied microscopically.

Megascopic characters.—In the hand specimen the granular olivine is penetrated in every direction with numerous glistening needles of a colorless amphibole, and contains scattered flakes of green chlorite. The rock is dark greenish gray in color.

Microscopic characters.—In thin section olivine is found to be greatly predominant, and is remarkably fresh, showing no trace of alteration of any kind involving hydration, except the occasional small flakes of chlorite. Colorless amphibole in slender needles, and also stouter prismatic individuals penetrate the olivine in every direction. Some of these are beginning to alter to talc. Numerous basal sections exhibit the prismatic outline and cleavage and the optical characters of tremolite or cummingtonite. From its close analogy to the occurrence at the Sapphire mine, described below, it is probably cummingtonite.

Chromite is abundant in irregular grains, chiefly opaque but occasionally showing a brownish translucence. Most of the grains are partially or wholly wrapped in a thin, irregular development of chlorite. The latter, both with the chromite and in scattered flakes through the olivine, exhibits a weak dichroism in sections cut across the cleavage—pale green for vibrations parallel, yellowish for those at right angles to the cleavage. So far as observed the rock is entirely free from enstatite.

DUNITE OF THE ASBESTOS MINE.

At this locality the greater part of the mass is dunite, enstatolite (enstatite rock) occurring only in subordinate masses in the southeastern portions.

Megascopic characters.—The rock is a fine-grained aggregate of grayish green olivine, with spots and streaks of darker color, almost black. Penetrating the mass in every direction are numerous, slender, glistening needles of colorless amphibole, probably cummingtonite.

Microscopic characters.—The olivine closely resembles that of the Bad Creek mine, but is not quite so fresh, showing slight alteration along some of the cracks to light-green serpentine, and considerable darkening by the accumulation of secondary oxide granules along the fissures.

Chromite occurs in numerous grains, some of which show crystal boundaries, and nearly all are more or less wrapped in chlorite, by which the grains are almost completely separated from the olivine. Among the bands and clusters of dark ore granules along the cracks of the olivine, doubtless chiefly magnetite, are occasionally found aggregates and streaks that are largely translucent and deep red in color; these are believed to be hematite.

Cummingtonite (amphibole-anthophyllite) in numerous small slender needles penetrates everywhere. It exhibits abundant cross-fracturing, and is sometimes partially altered to talc. The individuals are sometimes frayed out at the ends into tufts of radiating fibers. Its optical and crystallographic characters agree with either cummingtonite or tremolite, but from its close similarity to the Sapphire occurrence, described below, it is probably the former.

DUNITE OF THE SAPPHIRE MINE.

Megascopic characters.—The rock is chiefly fine-grained olivine, varying in color from light greenish gray to very dark grayish green and almost black. There are also visible numerous tremolite-like needles and small rounded grains of chromite. The latter are strongly magnetic and were at first thought to be magnetite, but in bead test with sodium-ammonium phosphate they give strong reaction for chromium.

Portions of the darker variety of dunite are thickly netted with interlacing talc veins, usually about one-fourth inch in thickness. These are often arranged in one or more parallel sets, sometimes crossing each other at approximately right angles, and only one-half to one inch apart.

Microscopic characters.—The olivine is very fresh with the exception of slight alteration to serpentine along some of the cracks. The section cut from a specimen with numerous talc veins shows considerable cleavage developed in the olivine, besides a great increase in the amount of irregular fracturing. The rock thus appears to have a very fine-grained texture, though the original size of the grains may be often seen by the large areas in the sections that show the same optical orientation.

The chromite occurs in large and small irregular masses, often surrounded by chlorite; it also frequently has skeleton-like forms. The chlorite occurring with the chromite, and also in occasional separate flakes, is slightly dichroic; pale yellow at right angles to the cleavage and light green parallel to it.

Cummingtonite (amphibole-anthophyllite) in slender needle-like forms and occasional stouter individuals penetrates the olivine in every direction, the longer needles passing through many olivine grains. It is greatly cross-fractured and is slightly altered to talc in places. Frayed out fibrous ends are sometimes seen. The characters observed under the microscope agree equally well with cummingtonite or tremolite, but tests of portions of the rock filled with the mineral failed to show the presence of calcium, and hence it must be regarded as cummingtonite, or amphibole-anthophyllite (Pl. XLII, fig. 6).

The talc of the veins polarizes chiefly in large cleavable plates. On the borders of the veins it is more or less intermingled with olivine and cummingtonite, the latter being often bent and split into numerous fibers in such cases. Occasional grains of carbonates also occur in the talc veins.

VICINITY OF GLENVILLE.

Of the numerous peridotite outcrops in the vicinity of Glenville, thin sections were prepared only from the harzburgite at Thompson Wilson's on Big Ridge, 1½ miles northeast of Glenville, and from the amphibole-peridotite on the northeast slopes of Shoal Mountain, 3 miles northwest of Glenville.

HARZBURGITE ON BIG RIDGE.

In an outcrop about 100 feet wide enstatolite (enstatite rock) largely predominates, much of it being finely fibrous or altered into the asbestiform chrysotile. By the introduction of olivine, however, the harzburgite facies is developed, and some portions seem to be composed almost exclusively of olivine.

Megascopic characters.—In the hand specimen, besides dark-green granular olivine, chlorite scales and slender needles of colorless amphibole are visible in considerable abundance, and less frequently the broad cleavage faces of enstatite.

Microscopic characters.—Olivine, formerly coarse-grained but now much fissured, constitutes the bulk of the rock. It looks perfectly fresh everywhere, no trace of alteration to serpentine appearing. Numerous slender needles of colorless monoclinic amphibole, probably cummingtonite, penetrate the olivine in every part of the section. Enstatite occurs in broad rounded areas, up to 10 mm. in diameter, and is also pierced in all directions by the amphibole needles. The enstatite is colorless and non-pleochroic.

Chlorite is developed in broad scales and felty masses throughout the rock, both in the olivine and the enstatite. It is uniformly dichroic, displaying weak tones of yellow and green. A little talc has been formed in portions of the enstatite. Irregular grains and aggregates of small granules of secondary magnetite are distributed through the sections, sometimes in well-defined bands. A few scattering grains of carbonates are also found.

AMPHIBOLE-PERIDOTITE OF SHOAL MOUNTAIN.

Megascopic characters.—On the outcrop the rock appears to be chiefly a compact chlorite penetrated by a mineral of small elongated form with glistening cleavage planes. The color is a uniform dark green.

Microscopic characters.—Scattering grains and clusters of perfectly fresh olivine are uniformly distributed through the rock. The most abundant primary constituent, however, is a light-green amphibole (actinolite) which occurs in somewhat elongated irregular individuals. Basal sections frequently exhibit prismatic outline, but terminal faces are uniformly wanting. The fresh individuals have a weak but distinct pleochroism: $\mathfrak{a}$ = pale yellow; $\mathfrak{b}$ = yellowish green; $\mathfrak{c}$ = light green. Absorption: $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. Much of the amphibole has become entirely decolorized, and has black oxide granules segregated in the prismatic cleavage cracks. Much of it is also partially or wholly altered to chlorite, which appears in thick cleavable plates with yellowish and greenish pleochroism. Chlorite of this nature constitutes more than half of the mass of the rock, judging from the section and character of the outcrop; and most of it has doubtless been derived from the alteration of the amphibole. A few grains of carbonates were observed in the section.

VICINITY OF FRENCH BROAD RIVER.

Several sections were studied from the dunite and serpentine outcrops that constitute the well-defined peridotite belt crossing the French Broad River 7 miles northwest of Asheville, one mile above Alexander. The belt is particularly well developed from Newfound Creek, 5 miles southwest of the river, to Flat Creek, 5 miles northeast. Over the greater portion of this distance the outcrops are chiefly serpentine, with minor developments of talcose rocks: unaltered peridotite is rare.

A few sections were also prepared from related rocks northwest of this belt, in the vicinity of Marshall.

FRENCH BROAD DUNITE.

No dunite outcrop, recognizable as such, was found nearer the French Broad than the small masses associated with the serpentine 3 miles southwest of the river, on Newfound Creek. In the opposite direction, 4½ miles northeast of the river, by the ford of Little Flat Creek, fresh dunite is again encountered.

Megascopic characters.—At both of these localities, the dunite is fine-grained and varies in color from light yellowish and grayish green to dark green. Small grains of chromite are sparsely disseminated through the rock and also small glistening scales of talc and chlorite. At both places it is distinctly, though not highly, laminated.

Microscopic characters.—In natural light the sections from both outcrops are fine grained, averaging usually 0.1 to 0.2 mm. in diameter, and the result of shearing is distinctly seen in the arrangement of the grains of the Little Flat Creek specimen (Pl. XLIV, fig. 1). In both, when viewed between crossed nicols, the small grains are found to extinguish together over considerable areas. This character is most marked in the rock from Newfound Creek, in which the areas of the same orientation are 1 to 2 mm. in diameter showing distinctly the manner in which a fine-grained rock has been produced from one of coarse texture. In the slight shearing and granulation a little fine scaly talc and chlorite have often been developed between the grains. In the Flat Creek rock, narrow strips of serpentine usually separate the olivine grains, and talc occurs in occasional large cleavable flakes, apparently from enstatite.

Octahedral crystals and irregular grains of chromite are found in the sections from both localities.

FRENCH BROAD SERPENTINE.

(1) On Newfound Creek just below the mouth of Dicks Creek is a light yellowish green serpentine with a slightly mottled granular appearance. It contains scattered grains of chromite, and the approximately parallel arrangement of thin black lines gives it the appearance of having been subjected to slight shearing.

Microscopic characters.—Under the microscope the serpentine exhibits well-developed mesh structure in some places, and the arrangement of the black granules often marks out distinctly the original olivine grains. The serpentine of the meshes is finely banded, and the higher powers exhibit a fibrous structure at right angles to the banding. The black granules are sometimes collected about the larger grains like iron filings at the poles of a magnet (Pl. XLIV, fig. 2).

(2) One-fourth of a mile south of the French Broad a very light-gray serpentine occurs with very slight granular mottling, and speckled with grains of chromite and magnetite. The development of a radiating mineral in the joints sometimes forms sheaths entirely enclosing large masses of the rock. The mineral is in fine fibers and needle-like individuals approximately at right angles to the walls between which they are formed. Except in structure, the sheaths have the same general appearance as to color, etc., as the mass of the rock.

Microscopic characters.—The rock shows considerable development of mesh- or net-structure, though the oxide granules are irregularly banded and grouped and only occasionally mark the boundaries of the original olivine grains. The chromite grains and larger groups of oxide granules are often partially or wholly surrounded by parallel or radiating chlorite. The mineral of the radiating sheaths has altered to serpentine, retaining the form of the fibers and needles of the parent mineral. From analogy with the fresh mineral of the Reems Creek locality (No. 4 below), it seems highly probable that this mineral was originally gedrite (Pl. XLIII, fig. 4). On the inside of such sheaths, next to the inclosed serpentine, confused aggregates of smaller bundles of fibers are sometimes found. A whitish, kaolin-like material, nearly opaque and sometimes stained brownish with iron oxides, forms small veins and irregular aggregates through the radial portions.

(3) On the south bank of the French Broad, 1¼ miles above Alexander, an outcrop of dark-green serpentine 15 feet wide is crossed by the railroad. The fresh fracture is flecked with small pearly scales of chlorite, and scattered grains of chromite also appear.

Microscopic characters.—In thin section the serpentine is light greenish yellow, and much of it has a parallel arrangement that indicates shearing. The black oxide granules also have a somewhat similar arrangement, but in other portions they sometimes outline the original olivine grains. Chlorite scales appear in parallel and radial bunches, and thin veinlets of carbonates traverse the section.

(4) On Reems Creek, three-fourths of a mile from the river, a very compact, dark-green and yellowish green serpentine occurs. Flakes of talc and a few small black grains are scattered through the mass. Enclosed in the serpentine are nodules, up to 2 feet in diameter, of a light-gray, confusedly fibrous mineral; these are enclosed in a radiating sheath of the same mineral in larger individuals, separating the nodules from the serpentine.

Microscopic characters.—Under the microscope the serpentine is colorless. A well-developed mesh-structure and the distribution of the ore granules distinctly mark out the boundaries of the original olivine grains. Sections of the nodules in the serpentine exhibit a fibrous colorless mineral with numerous cross fractures, a high mean index of refraction and very strong double refraction. Basal sections show the prismatic cleavage of amphibole, and the optical orientation is: $a = \mathfrak{a}$; $c = \mathfrak{c}$. The axial plane is 010, and the optical character is negative. These properties correspond in every respect with the orthorhombic amphibole, gedrite.

As a rule, the gedrite is perfectly fresh looking, but in some places it shows considerable alteration to fine scaly talc and, in smaller amounts, to chlorite. Streaks and bunches of segregated oxides in other portions also doubtless represent the initial stages of alteration. The fresh mineral from the nodules and from the radiating sheaths, respectively, is shown in Pl. XLIII, figs. 5 and 6.

(5) One mile northwest of Weaverville, and a half mile north of the Weaverville-Alexander road, a dark, massive serpentine occurs with great development of schistose talc in the joints, and presenting the surface appearance of a soapstone outcrop.

Microscopic characters.—Microscopic examination shows a colorless to light-yellow serpentine with well-developed mesh-structure, which, with the bands of oxide grains, outline the original grains of olivine. Darker yellowish spots in the midst of the meshes also mark the remnants last altered to serpentine (Pl. XLIII, fig. 3).

MICA-DIORITE AND AMPHIBOLITE NEAR MARSHALL.

Three miles east of Marshall and one-half mile north of the mouth of Ivy River, a massive, coarse, green amphibolite forms the principal part of an outcrop several hundred feet across, its form and extent not being exactly determined. In smaller masses the rock is mottled with considerable feldspar and contains a large proportion of biotite, forming a mica-diorite. The rock is thoroughly decomposed over a large part of the outcrop, giving rise to abundant honeycombed chalcedony. Numerous corundum crystals have been found over the surface.

Microscopic characters.—The amphibolite in thin section shows only light-green amphibole in broad rounded plates. It is slightly pleochroic in light-green and yellowish green tones. Some portions are considerably darker green and are filled with oxide granules evenly distributed or collected into bands and patches. Other parts show the effects of shearing and crushing.

In the mica-diorite the amphibole occurs in short, irregular grains and somewhat elongated laths, with schistose arrangement, and is more distinctly pleochroic: $\mathfrak{a}$ = pale yellow to yellowish green; $\mathfrak{b}$ = yellowish green; $\mathfrak{c}$ = green. Absorption $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$.

The plagioclase is in large rounded masses with multiple twinning abundant but not universal. It is almost entirely fresh, showing only brownish dusty streaks in places. Inclusions of smaller grains of amphibole and biotite, and sometimes large ones, are abundant; also numerous rounded grains of zoisite.

The biotite occurs in large cleavable plates and, like the amphibole, has a roughly parallel schistose arrangement. The color is yellowish brown, and sections across the cleavage exhibit strong pleochroism, dark yellowish brown parallel to the cleavage, pale yellow to almost colorless for rays vibrating at right angles to the cleavage. Sections parallel to the cleavage show very slight pleochroism, and in convergent light show a very small axial angle, almost uniaxial. The biotite occasionally includes plagioclase and amphibole, besides numerous black oxide grains and rounded grains of zoisite (Pl. XLIV, fig. 3).

Numerous rounded grains, usually somewhat elongated, with cleavage well developed parallel to the elongation, are included in the feldspar and biotite. They have a high index of refraction and their double refraction is somewhat weaker than that of the plagioclase; characters that coincide with those of zoisite.

Large pink garnets, almost colorless in thin section, are not uncommon.

PERIDOSTEATITE AT THE MADISON COUNTY HOME.

This is a somewhat schistose olivine-talc rock, the olivine areas forming dark-gray to nearly black patches mottled and streaked with white and light-green talc. In appearance it bears a close resemblance to the peridosteatite near Bryn Mawr, Pennsylvania. The proportions of talc and olivine vary considerably in different parts of the outcrop.

Microscopic characters.—Evidences of shearing are distinctly seen in all the constituents in thin section. The olivine is very much fissured, but still extinguishes together over large areas, indicating that the rock was originally coarse textured. In places it is much darkened by oxide granules, and shows a very slight alteration to serpentine. The talc occurs chiefly in felty masses with aggregate polarization. Occasionally it is in large cleavable plates. Chlorite, in very much smaller amounts, also occurs in the same forms. Magnesite forms large granular areas in the section, the individual grains usually showing rhombohedral cleavage.

PERIDOTITES ON IVY RIVER.

CARTER MINE DUNITE.

The large dunite mass in which the Carter corundum mine is located is composed of a fine-grained laminated rock, varying in color from light yellowish green to dark green and almost black. With the exception of occasional grains and crystals of chromite, no other constituent but the olivine is visible.

Microscopic characters.—Most of the sections show a very fine-grained rock, the grains averaging .1 to .2 mm. in diameter, but with crossed nicols these are found to polarize together over considerable areas, showing the grains to have been originally 0.6 to 1 mm. in diameter (Pl. XLIII, figs. 1, 2). In some places the orientation of the fissured grains has been partially or wholly destroyed by movements that have rolled the fragments somewhat upon each other. In all cases the granules are separated from each other by thin development of yellowish or greenish serpentine. Masses that look almost black in the hand specimen show, in thin section, light-green serpentine heavily charged with magnetite granules surrounding the colorless olivine.

Sections of octahedrons and irregular grains of chromite are disseminated through the slide. Several of these have reëntrant outlines and some are deeply embayed. Thin scales of chlorite are occasionally observed, and irregular patches of finely felted talc. In one section (A27) a large area of talc which exhibits confused aggregate polarization, has in natural light the general appearance and characteristic *schiller* interpositions of enstatite.

One section (A26) is normal dunite, without the fine granulation of the olivine, and shows the beginning of alteration to yellowish serpentine in a typical manner.

SERPENTINE OF PAINT FORK.

Some portions of the light yellowish green serpentine on Paint Fork, 3 miles north of the Carter mine, contain abundant remnants of olivine that are visible in the hand specimen.

Microscopic characters.—In thin section much of the serpentine is pale yellow to almost colorless, with irregular aggregates of magnetite in honey-yellow serpentine marking the positions of the last remnants of olivine to be altered, and fibrous, brightly polarizing serpentine indicating the original boundaries of the grains (Pl. XLIV, fig. 4). In the portions that still contain considerable olivine, the original outlines of the grains are marked by streaks of brownish dust. Octahedrons and irregular grains of chromite occur somewhat plentifully.

PERIDOTITES OF YANCEY COUNTY.

DUNITE OF PRICE CREEK.

The rock is fine grained, light grayish green, with occasional chromite crystals visible.

Microscopic characters.—In thin sections it shows the typical characters of an allotriomorphic granular dunite, which has suffered only the slightest beginning of alteration to serpentine. Besides the sections of chromite crystals, numerous small grains and dust-like particles of magnetite are gathered into clusters and arranged along the boundaries of the olivine grains where a very thin film of serpentine has been formed. Occasional elongated needles of colorless monoclinic amphibole are seen, many of them partially or almost wholly altered to talc. Other and somewhat larger areas of talc contain some of the characteristic *schiller* inclusions of enstatite. Occasional flakes of chlorite are also encountered.

DUNITE AT THE HAYES (EGYPT) MINE.

This is a dense, greenish black rock in which colorless amphibole is distinctly visible in the hand specimen.

Microscopic characters.—Thin sections show a fine-grained rock derived from one of coarse texture by extensive fracturing of the olivine, which still polarizes together over large areas. It is somewhat altered along the borders to talc and chlorite, and frequently also along the smaller fissures and cleavage planes as well, but no serpentine has been formed. Colorless amphibole in slender needles and stouter individuals is frequently seen, and is usually more or less altered to talc (foot-note p. 67). Talc and chlorite form numerous large cleavable plates and irregular areas with aggregate polarization, and large irregular masses of magnetite are numerous. Carbonates form granular cleavable masses in considerable abundance in portions of the rock.

MICA-DIORITE AT THE HAYES (EGYPT) MINE.

This dense, greenish black rock, apparently consisting chiefly of hornblende flecked with small whitish grains of feldspar, accompanies the dunite outcrops at the Egypt mine. It has a quite distinct schistose structure.

Microscopic characters.—About three-fourths of the bulk of the rock consist of green hornblende, which shows a distinctly schistose arrangement in thin section. It is pleochroic: $\mathfrak{a}$ = light yellow, $\mathfrak{b}$ = yellowish green, $\mathfrak{c}$ = green. The absorption is: $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$, and the extinction, $\mathfrak{c} \wedge c$, is near 20°. Plagioclase feldspar occurs in irregular rounded grains, and exhibits very little multiple twinning or cleavage. Biotite occurs in small plates and clusters throughout the rock. It is strongly pleochroic, rays vibrating parallel to the cleavage being dark reddish brown, while for vibrations perpendicular to the cleavage the color is pale yellow to almost colorless. Magnetite occurs in numerous irregular grains and patches and in elongated streaks parallel to the schistosity.

ANORTHOSITE AT THE HAYES (EGYPT) MINE.

Massive white feldspar rock appears along the borders of some of the corundum workings at this locality. Disseminated throughout the rock, and giving it a peculiar speckeled appearance, are small rounded clusters of brownish minerals, one-eighth to one-fourth inch (3 mm. to 6 mm.) in diameter and one-fourth to one-half inch (6 mm. to 12 mm.) apart. Immediately around each cluster the feldspar is stained a bright emerald-green.

Microscopic characters.—The thin sections are occupied chiefly with broad areas of plagioclase feldspars, which show abundant multiple twinning. Occasional flakes of brown biotite are uniformly distributed through the rock. The feldspars are plentifully sprinkled with small crystals and irregular grains of zoisite and epidote (Pl. XLIV, fig. 5), varying in size up to 0.5 mm. by 2 mm. in rare cases. The clusters of brown minerals that are so prominent in the hand specimen are found to be groups of zoisite, epidote, and biotite.

The epidote is usually somewhat larger than the accompanying zoisite, and is almost invariably associated with biotite, even when scattered through the feldspar. The crystals are generally distinctly elongated parallel to the axis of symmetry, cross-sections showing the following forms: base, (001); orthopinacoid, (100); and positive hemi-orthodome, $(\bar{1}01)$. Sections parallel to the *b*-axis are without terminations. Basal cleavage is well developed, and cleavage almost equally good parallel to the orthopinacoid. Twinning parallel to the orthopinacoid is also common (Pl. XLIV, fig. 6). The crystals exhibit the characteristic optical properties of the species: the plane of the optic axes is the plane of symmetry, with the negative bisectrix almost coincident with the axis *c;* the sections exhibit strong relief and high interference colors; crystals that are distinctly colored are pleochroic, vibrations parallel to 𝔟 and 𝔠 being light yellow, and those parallel to 𝔞 colorless; others are so nearly colorless in all positions that no pleochroism is discernible.

The zoisite occurs in irregular grains and elongated prismatic individuals without terminal planes and without recognizable boundaries on any of the sections. It is plentifully disseminated through the feldspars, along with the epidote, which it closely resembles in natural light. The double refraction of the zoisite is so low, however, as to produce only a feeble "ultra blue" between cross nicols. It also differs from the epidote in its parallel extinction, and in the invariable absence of color and pleochroism. Twinning is discernible between crossed nicols in several instances.

Biotite occurs sparingly, but uniformly, distributed throughout the rock in small irregular flakes. Its color is yellowish brown for rays vibrating parallel to the cleavage, and pale yellow for vibrations at right angles to it. The almost constant association of this mineral with the epidote suggests that it was probably the source of iron for the latter; and the bright green halos surrounding the clusters of these minerals in the hand specimen are probably to be attributed to chromium from the biotite.

CHAPTER IV.

MODES OF ALTERATION AND DECOMPOSITION OF THE PERIDOTITES.

Olivine (chrysolite) is the chief constituent of the peridotites, and therefore an understanding of the alteration of these rocks must be based primarily on a comprehension of the properties of this mineral. It is an orthosilicate of magnesia represented by the formula $(Mg, Fe)_2SiO_4$, containing about 40 per cent of silica, the rest consisting of magnesia and ferrous oxide in widely varying ratios. A more complete mineralogical description is given in Chapter IX.

Few minerals are so susceptible to alteration, under present conditions at the earth's surface and at shallow depths, as olivine, and few give rise to such a great variety of secondary minerals. Five distinct processes of alteration and their resulting products are clearly discernible in the North Carolina peridotites, namely:

1. Weathering.
2. Serpentinization.
3. Steatitization.
4. Chloritization.
5. Amphibolization.

While all of these processes occur more or less together over wide areas, one or another usually predominates, and thus various parts of the peridotite belt are characterized by the abundance of certain alteration products—as serpentine, talc, chlorite, etc.—with smaller proportions of others. The processes of weathering and serpentinization, especially, are well-nigh universal, though developed to only a slight extent, relatively, except in a few localities. In fact the peridotites as a whole are remarkably fresh on the outcrops, and generally but little serpentinized. Alteration to talc, chlorite and amphibole are much more local in their manifestations, but have given rise to many important rock masses.

Most of these modes of alteration of the peridotites have been frequently well described by petrographers in this country and Europe during the past two or three decades. Hence little more than an outline of them is required here, with a designation of the chief localities where each is developed.

Since olivine (chrysolite) is the principal constituent of all peridotites, the manifold alterations of this mineral will necessarily constitute the first and most important consideration in the study of the alterations of the rocks that it composes. This is particularly true of dunite, the most abundant peridotite in North Carolina, which is essentially an olivine rock, with only small amounts of accessory minerals. In the descriptions that follow, therefore, the alterations of dunite are first considered and any modifications that occur in other peridotites are noted afterward.

WEATHERING.

The ferromagnesian orthosilicate, olivine, $(Mg, Fe)_2SiO_4$, yields readily to complete decomposition under the influences of the oyygen, moisture, and carbon dioxide of the air, and other weathering agencies, forming chiefly magnesium carbonate, hydrous iron oxides, and silica. Doubtless small quantities of iron carbonate are usually formed also, besides traces of chlorides, nitrates, and salts of the bases with organic acids formed by the decomposition of vegetable matter.

The carbonates are sometimes deposited in veins and irregular masses or scattered grains; but they are usually removed almost completely through the leaching effects of infiltrating waters, leaving limonite (or goethite) and chalcedony (or quartz).

The first traces of weathering are observed in the outcrop by the yellowish to brownish yellow color assumed and the accompanying friability of the rock. Under the microscope the color is seen to be produced by the separation of a portion of the iron in the form of a hydrous oxide, which is segregated along the cracks and borders of the olivine grains, the latter still remaining transparent and, to all appearances, perfectly fresh. If the olivine has been previously more or less serpentinized, the process of weathering is essentially the same, the separated iron oxide being mingled with the serpentine; but, so far as observed, there is no evidence in these rocks to indicate that alteration to serpentine is a necessary antecedent or accompaniment of weathering.

In the more advanced stages of weathering, the rock crumbles too easily to admit of the preparation of thin sections, the proportion of limonite powder gradually increases, and silica accumulates in reticulating veins or irregular nodules throughout the mass.

The hydrous iron oxide is doubtless usually limonite, though the analyses given below seem to indicate that, in the earlier stages of alteration at least, some of it may be goethite, which is a very similar mineral, though containing less water. In either case, the final result would be an ocherous pulverulent mass, with nodules and reticulating veins of chalcedony.

This residual limonite has been mined to a limited extent as an iron ore in certain portions of the Appalachian belt, but, so far as known, it has not been worked in North Carolina (see p. 399). Mr. Joseph Willcox[1] states that it was mined at several localities in Middletown Township, Delaware County, Pennsylvania, "but not with profitable results."

Dr. T. S. Hunt[2] gives the following description of the limonite ores that were formerly mined on Staten Island, New York:

> An instructive example of an analogous process is seen in the limonite which on Staten Island, New York, is found imbedded in a layer of brownish earthy material, sometimes attaining a thickness of 12 feet. This rests immediately upon the serpentine rock of the region, into which it graduates, and from the subaerial decay of which it has evidently been derived; the lower portion of the earthy matrix still preserving the peculiar jointed structure of the underlying serpentine. This decomposed material, though including botryoidal crystals, geodes, and concretionary grains of limonite, with occasional druses of chalcedony and of quartz crystals, retains considerable coherence.
>
> . . . . This limonite, which is now mined to a considerable extent, contains, as several analyses have shown, from one to two hundredths of chromic oxyd, which is also known to be present in small amount in the serpentine. An impure argillaceous specimen, containing only 59.63 of ferric oxyd, yielded the writer 2.81 of chromic oxyd in a condition readily soluble in chlorhydric acid.
>
> . . . . It is, I think, evident that the decay of the serpentine, and the concentration in the residuum, of its iron in the form of limonite, was a process anterior to the glacial erosion, and that the ore banks are areas of the decayed material which escaped this action.

Where more resistant minerals have been developed along the joints and cracks of the rock, as the sheathing of radial enstatite found at many peridotite localities in North Carolina (Pl. XIV, A), large blocks of the rock, apparently firm and solid, are found, on being broken, to have been completely altered into an ocherous mass that readily crumbles on exposure to the air. That this process proceeds from the joints into the adjacent rock is shown by the unaltered remnants of peridotite still found in the center of many such decomposed blocks.

In one locality, three-fourths mile southwest of Elf, Clay County, this process of decomposition has given rise to a number of limonite concretions in the form of hollow shells, or geodes, consisting of fibers of the mineral arranged at right angles to the surface. These shells are one-half inch to 1 inch in thickness and range in size to more than a foot in diameter. They are empty except for small amounts of fine, scaly vermiculites and talc lying loose in the hollow space. Adhering to the interior walls are also usually a few small, clear, drop-like masses of hyalite, a hydrous form of silica.

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[1] Second Geol. Surv. Pennsylvania, C4, 1883, p. 347.

[2] Mineral Physiology and Physiography, 1886, pp. 268, 269.

The silica resulting from the decomposition of the olivine rocks and serpentine usually assumes the compact, fine-grained form of quartz known as chalcedony. Its granular structure is generally invisible to the unaided eye (cryptocrystalline), but may be seen distinctly under the microscope. In the thicker nodules and irregular masses it is frequently more or less translucent, and sometimes encloses black, fern-like aggregates, probably an oxide of manganese, forming a variety similar in appearance to moss agate.

This residual silica is also often in the form of cellular or honeycomb-like rusty masses of quartz, which remain scattered over the surface, along with the denser, compact nodules, after the softer limonite has crumbled away. In this manner it accumulates in some localities in great abundance, sometimes bearing a close resemblance to the gossan of a ferruginous ore vein. This feature has been pointed out by Mr. Joseph Willcox[3] in his descriptions of the serpentines of Chester and Delaware counties, Pa., as follows:

> The cellular quartz, locally called honeycomb rock, is nearly always ferruginous; and it is a common, if not a constant associate of the serpentine. It often occurs in inconvenient profusion; and in many cases it is the only surface indication of the proximity of the serpentine rocks, the latter, near the surface, having been decomposed into soil.
>
> Ferruginous cellular quartz, similar in appearance to the Delaware county rocks, accompanies the chrysolite beds among the mountains in western North Carolina. It so forcibly resembles in appearance the superficial gossan at the Ducktown copper mines in Polk County, Tennessee, that many prospecting pits and trenches have been dug in North Carolina for copper ore where the ferruginous quartz occurs, the latter having been mistaken for gossan.

More recently similar decomposition products occurring over large areas in Maryland have been mistaken for gold ores, as described by Dr. F. Bascom:[4]

> . . . . There are pits in the serpentine made in search of gold ore, at the instigation of a syndicate known as "The Klondyke Company." This company purchased the option on considerable property to the north of Conowingo with the expectation of finding the rocks richly auriferous. The results did not meet their expectations, and the company has been inactive for more than a year.

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[3] Second Geol. Survey Pennsylvania, C4, 1883, p. 347.

[4] Maryland Geol. Survey, Cecil County report, 1902, p. 97.

The alumina which is always present in the peridotites in small amounts, during the process of decomposition takes the form of the hydrous silicate kaolin, and becomes relatively more abundant with the continued removal of magnesia by infiltrating waters.

The following analyses of dunite from Corundum Hill show the chemical changes occurring in the first stages of decomposition by weathering.

Analyses of Corundum Hill dunite.

[By T. M. Chatard, Bull. U. S. Geol. Survey No. 42. 1887, pp. 55, 56.]

	I.	II.	III.	IV.
SiO_2	40.11	40.25	40.18	40.04
Al_2O_3	.88	.96	1.35	3.17
Cr_2O_3	.18	....	1.41	....
Fe_2O_3	1.20	2.71	10.97	12.15
FeO	6.09	5.97	....	....
MgO	48.58	47.76	43.84	42.97
H_2O (Ign.)	2.74	1.54	2.01	2.14
Chromite	.56	....	....	.17
	100.34	99.19	99.76	100.64

I. Dunite,. crystalline granular, apparently least altered; subvitreous, grayish to oil-green in color.

II. Altered dunite, granular, dull; color, pale yellowish brown; from interior of altered nodule.

III. Altered dunite, granular, pulverulent, brownish yellow color; from outside portions of altered nodule, harder part.

IV. Altered dunite, softer and more easily pulverized part separated from III by crushing without grinding, and sifting through a fine sieve.

The gradual decrease in magnesia, with a corresponding increase in iron and alumina, is clearly seen. Unfortunately the ferrous and ferric iron were not separately determined in analyses III and IV, and hence their relations are not shown. An increase in ferric and a decrease in ferrous iron are shown, however, by analyses I and II, and similar changes doubtless continue through the series. The water varies somewhat in the materials used, but is practically the same in the last as in the first analysis. It doubtless belongs almost wholly to serpentine, however, in the first, and to limonite (or goethite) and kaolin in the last.

Analysis IV corresponds approximately to a rock of the following composition: Olivine 85 per cent, goethite 7 per cent, and kaolinite 8 percent, as exhibited in the following table of analyses.

Mineral composition of dunite of analyses IV.

	Olivine; 85 per cent.	Goethite; 7 per cent.	Kaolin; 8 per cent.	Total.	Dunite IV.
SiO_2	35.18	....	3.71	38.89	40.04
Al_2O_3	....	....	3.18	3.18	3.17
Fe_2O_3	....	6.29	....	6.29	12.15
FeO	6.55	....	....	6.55	....
MgO	43.27	....	....	43.27	42.97
H_2O	....	.71	1.11	1.82	2.14
	85.00%	7.00%	8.00%	100.00	....

Plate XIV, B, shows a typical weathered surface of dunite exposed near Webster, Jackson County, N. C. Small veins of talc developed through the rock, on account of their greater resistance to weathering, stand out on the surface in little projecting ridges.

The presence of enstatite in addition to the olivine as a constituent of the rock forms harzburgite (or saxonite). The weathering of this does not differ essentially from that of dunite, except that the enstatite frequently alters into talc, which is a more resistant mineral than olivine; and hence it usually stands out in little knots on the surface of the exposed rock (Pl. XV, A). Scales of talc are also often abundant in the ocherous mass resulting from the decay of the rock in place.

In extremely pyroxenic facies of harzburgite, bordering on the pyroxenites, the previous hydration of the enstatite, producing talc, gives rise to a rock (periodosteatite) that is quite stable under exposure. Only the olivine yields readily to decomposition, and the ferruginous products stain the rest of the rock, making a rusty soapstone. Where the original olivine grains were large, their decay has left the mass of the talc full of holes containing the powdered ocher. Such rocks have been observed at Sapphire, and near Balsam Gap, Jackson County; near the county home, Madison County; in many localities in Ashe and Alleghany counties; and extending across the State line into the southwestern border of Virginia.

In the amphibole-peridotites, the green amphibole has been frequently altered, in the exposed portions of the rock, to chlorite. On bare exposures this mineral is also more resistant than the olivine, and forms little knotty projections on the surface of the rock. Where residual products of weathering accumulate, however, and the decomposing mass is continually permeated by moisture, chlorite readily alters to vermiculites, and ultimately decomposes into an ocherous clay, the magnesia being removed by percolating waters, as in the case of olivine. The proportion of clay in the final product manifestly depends on the extent to which the original amphibole was aluminous and the proportion of this mineral in the rock.

In the troctolites, which consist of olivine and anorthite, the latter mineral loses its lime by decomposition and changes to kaolin. The olivine alters as in the other peridotites. Hence the final result is very similar to that reached in other cases, except that the clayey constituent is considerably increased. The amount of clay in the residuum, however, depends, not upon variation in the constitution of the mineral producing it, but upon the varying proportions of anorthite present. The slightly feldspathic peridotites give rise, therefore, to little clay, while those facies in which anorthite predominates, the olivine-anorthosites, produce chiefly clay, with a ferruginous or rusty discoloration.

The more or less complete alteration of the peridotites into serpentine does not affect the nature of the final products of weathering, and apparently causes little, if any, difference in rate of decomposition. Both are readily decomposed; but, when occurring in massive bodies, they are also frequently more resistant to weathering than the thinly laminated gneisses and schists surrounding them.

Thus it is seen that the ultimate products of complete decomposition by weathering are practically the same for all the perdiotites of the region, and for the serpentine into which they may have been altered. They differ chiefly in the proportion of kaolin, or clay, in the mass, this being smallest in the residua of dunite and harzburgite and increasing in amphibole-peridotite and troctolite.

The chromite, which is universally present in greater or less amount in the peridotites and in serpentines derived from them, is a very stable mineral, and does not yield to the forces of weathering that decompose the other constituents of the rock. Hence grains and nodules of this mineral, sometimes of considerable size, accumulate on the surface and throughout the ocherous soil, and are sometimes concentrated in the near-by streams. In Pennsylvania and Maryland considerable quantities of chromite have been mined from these resulting placer deposits, but no workable deposits of this character have been found in North Carolina.

SERPENTINIZATION.

The alteration of the peridotites to serpentine is chiefly due to the hydration of the olivine; that is, to its combination with a definite amount of water. The composition of olivine is represented by the formula, $(Mg, Fe)_2SiO_4$, or $2(Mg, Fe)O.SiO_2$, and that of serpentine by $H_4(Mg, Fe)_3Si_2O_9$, or $3(Mg, Fe)O.2SiO_2.2H_2O$. The serpentine molecule expressed by the latter formula is equivalent to twice the olivine molecule after the removal of one-fourth of the basic oxides, including most of the iron, and the addition of two molecules of water. This relation is expressed by the following equation:

$$\underset{\text{(Olivine)}}{2(\mathrm{Mg, Fe})_2\mathrm{SiO}_4} - \underset{\substack{\text{(Iron and}\\\text{Magnesia)}}}{(\mathrm{Fe, Mg})\mathrm{O}} + \underset{\text{(Water)}}{2\mathrm{H_2O}} = \underset{\text{(Serpentine).}}{\mathrm{H_4Mg_3Si_2O_9}}$$

Dr. H. Rosenbusch[5] suggests that probably serpentinization is the first step in the decomposition of olivine into carbonates, silica, and limonite by the process of weathering. There seems to be no evidence, however, that such is ever the case in the peridotites of North Carolina The universal presence of oxygen and carbonic acid in weathering, two agents that are very active at the earth's surface and have strong affinity for the basic elements of olivine, tends to promote complete decomposition with the formation of simpler compounds, as described above, and thus to prevent the formation of the complex hydrous silicate, serpentine. This is true in the great majority of cases at least, and probably in all cases.

Serpentinization, therefore, is believed to be a process that can take place only below the depth of active weathering. The active circulation of water from the surface practically extends surface conditions, more or less subdued, down through the rocks to some depth. On this hypothesis, serpentine could exist at the surface only where a certain amount of overlying rock has been decomposed and removed after the alteration of the peridotite into serpentine.

The process always begins on the surfaces and in the cracks of the olivine grains. The first serpentine formed is often fibrous and is arranged directly across the cracks in which it is produced. If the olivine contains much iron, some of it is usually separated from the mineral in the form of small grains and dust-like particles, which accumulate around the outside of the olivine grains, thus forming an irregular dotted line, as seen in cross-section, through the midst of the first formed serpentine (Pl. XXXV, figs. 4, 5, 6). The bulk of the serpentine is slightly greater than that of the olivine from which it is derived, and hence considerable strain is produced by swelling as the hydration proceeds. This often cracks the olivine, especially if it is coarse grained, and thus produces new channels for the admission of water to augment the rate of alteration. The process may be found in all stages of advancement, from the thinnest sheaths of serpentine that first enclose the olivine grains to their complete alteration into massive serpentine-rock. Several of these stages are shown in the photomicrographs of plates XXXV and XLI.

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[5] Mikroskopische Physiographie, Vol. I, 3d edition, 1892, p. 471.

In the more ferriferous olivines magnetite granules and aggregates are not only formed about the boundaries of the grains in the first stages of alteration, but are also often massed about the last surviving remnants or cores of unaltered olivine. (Pl. XLI, fig. 4.) When the proportion of iron is not excessive, it is also frequently concentrated into the central parts of the olivine grains, as alteration proceeds, without separation into oxides. Thus the last formed serpentine in the center often has a dark yellowish brown color, as seen in Plate XLIII, fig. 3.

The occluded iron sometimes takes the form of the higher oxide, hematite, but such cases are very rare. This fact points to the scarcity or almost total absence of atmospheric oxygen during the formation of the serpentine, otherwise the iron would undoubtedly assume the form of the higher oxide in most cases.

Small amounts of serpentine are dissolved by the water that penetrates the rock during the process of alteration, and the reprecipitation of this gives rise to thin veins and seams of the massive translucent variety called precious serpentine, in the joints and other cracks of the rock. Sometimes veins are also formed of the fibrous silky variety, chrysotile, frequently called "asbestos." Although not the true mineralogical asbestos, which is a fibrous amphibole, this mineral is marketed under the same name and has considerable value (see p. 390).

Sepiolite, or meerschaum, a hydrous magnesium silicate of nearly the same composition as serpentine, is sometimes formed in small amounts during the process of serpentinization of the peridotites. Some of the nickel-bearing silicates at Webster are sepiolite in which part of the magnesia is replaced by nickel (see p. 329).

Nickel also often forms with magnesia other hydrous silicates, such as genthite, garnierite, etc., which are very similar chemically to serpentine and sepiolite. These sometimes segregate into veins and irregular masses of sufficient extent to form an ore of nickel (see p. 398). Dr. F. W. Clarke[6] has shown that these and similar nickel ores in Douglas county, Oregon, and the island of New Caledonia have probably originated from the alteration of nickeliferous olivine in peridotites.

When enstatite is a constituent of the rock, as in harzburgite, it is sometimes found to be altered into serpentine, though usually its hydration gives rise to talc. Under similar conditions, amphibole

[6] Am. Jour. Sci., 3d Series, Vol. XXXV, 1888, pp. 483-488.

usually alters to chlorite; hence chloritic serpentines are produced from amphibole-peridotites, as at Buck Creek.

Chromite and related minerals that may be present in the original peridotites remain unaltered in the serpentine, withstanding both the alteration processes of the zone of hydration and the decomposing forces of the zone of weathering. What is apparently an exception to the absolute stability of chromite is the occurrence in it of minute scales and incrustation of kämmererite, a reddish chromiferous chlorite. This mineral has been observed in the chromite masses associated with peridotites that are more or less aluminous in several localities (see p. 319).

STEATITIZATION.

The alteration of olivine into talc has been frequently observed in the peridotites, and in some cases this process has given rise to secondary compact or schistose rocks that may be called steatite or soapstone. Hence it is proposed that the process be called steatitization, in conformity with the well recognized term, serpentinization.

This mode of alteration is not described by either Rosenbusch or Zirkel, although the latter[7] remarks that alteration into talc not infrequently occurs. Evidently these eminent authorities regard it as of minor importance. From the study of the peridotites of North Carolina and of several other portions of the Appalachian crystalline belt, however, this process is found to be of sufficient magnitude to warrant its being recognized as a distinctive mode of alteration, comparable in importance with serpentinization. It was clearly distinguished and described by Dr. A. A. Julien[8] in the North Carolina rocks, in 1882, as follows:

> The development of the talc scales throughout a dunite is brought about in two ways: By the conversion of the olivine grains, partially or completely, into talc, which either envelopes them as a microscopic crust, with an ocherous core (i. e., the separated iron oxide), or has crystallized out in scales among the interstices of the olivine granules; or again, by the alteration of the actinolite fibers and grains into talc, which is then seen as fibrous pseudomorphous films or scales within the cleavage planes of the actinolite, or entirely replacing it. The process has often attacked the rock in both ways in the same mass, and has resulted in the production of talcose dunite, talcose actinolitic dunite, talcose amphibolites, and actinolitic steatite and talc schists.

The actinolite referred to by Dr. Julien is here regarded as a primary mineral, and hence the rock to which it belongs is to be classed as an amphibole-peridotite and not a dunite.

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[7] Lehrbuch der Petrographie, 2d edition, 1893, Vol. I, p. 357.

[8] Proc. Boston Soc. Nat. Hist., Vol. XXII, 1882, p. 141.

Dr. F. A. Genth[9] has also ascribed the talc associated with the North Carolina peridotites to the alterations of these rocks. He says:

> Resulting from the alteration of chrysolite, foliated talc of a white or greenish white color is found in many of the chrysolite beds west of the Blue Ridge; Shooting Creek, Clay County; Cullasagee, Macon County; Webster, Jackson County; Hampton's Mining Creek, and Young's on South Toe River, Yancey County; near Bakersville, Mitchell County, and other localities.

Chemically the process of steatitization of olivine, the chief constituent of the peridotites, consists in the loss of practically all of the iron and a large part of the magnesia of the original mineral, and the addition of a small quantity of water. The transformation may be represented theoretically by the following equation:

$$\underset{\text{(Olivine)}}{4(\mathrm{Mg, Fe})_2\mathrm{SiO}_4} - \underset{\substack{\text{(Iron and}\\\text{Magnesia)}}}{5(\mathrm{Fe, Mg})\mathrm{O}} + \underset{\text{(Water)}}{\mathrm{H_2O}} = \underset{\text{(Talc).}}{\mathrm{H_2Mg_3(SiO_3)_4}}$$

The excess of magnesia chiefly forms the carbonate, and is either deposited, or, as is usually the case, entirely removed from the rock in solution. In some cases, appreciable amounts of it are scattered through the talc, or accumulated into veins and irregular nodules. The iron separates out in the form of minute, dust-like particles of magnetite, which often accumulate in thin films and irregular nodules and patches through the secondary talc. In some cases, however, perfect octahedral crystals of magnetite have been observed in a very foliated variety of talc, such as occurs at the Woody farm, in Mitchell County. This is probably to be regarded as a recrystallization of the iron oxide, which is separated from the altering silicate in the form of amorphous films and granules, as described above.

The beginning of this process of alteration can be found in all kinds of peridotites that occur in western North Carolina, and is usually recognized by the small, glistening flecks of talc visible in the hand specimen. Under the microscope minute scales of this mineral are found to have developed, in such cases, about the borders and along the cracks of the olivine grains, and are arranged more or less nearly parallel to these surfaces or in confused felty aggregates. In pyroxene and amphibole the scales usually develop along cleavage cracks and gradually replace the original mineral, forming a pseudomorph.

As pointed out in the description of serpentinization (p. 118), the pyroxene of harzburgite, the olivine-enstatite rock, is often altered to talc. This has frequently given rise to olivine-bearing steatite, or peridosteatite, and, by the subsequent weathering out of the olivine, to ferruginous steatite, or rusty soapstone. The alteration of the olivine as well as the enstatite of these rocks into talc has undoubtedly produced the numerous gray and white soapstone masses associated with them, as well as the similar rocks occurring in many localities as continuations of the dunites, or as the disconnected representatives of them. In the case of the amphibole-peridotites, both the olivine and the amphibole have been found altering into talc, though usually more or less chlorite is also formed; and frequently the latter mineral predominates in the secondary rock.

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[9] Bull. U. S. Geol. Survey No. 74, 1891, p. 61. See also Am. Jour. Sci., 2d series, Vol. XXXIII, 1862, p. 200.

CHLORITIZATION.

The alteration of olivine to minerals of the chlorite group (prochlorite, clinochlore, etc.) involves the loss of magnesia and the accession of alumina and water. Analyses of dunite usually show a small amount of alumina, but not enough to permit the alteration of more than an insignificant part of the rock to chlorite. Hence, it must be assumed that the rock has been penetrated by infiltrating solutions, which have supplied the requisite water and alumina and have removed or deposited the excess of magnesia in form of the carbonate. Using the formula of clinochlore as a representative of the chlorite group, the reactions may be theoretically stated as follows:

$$\underset{\text{(Olivine)}}{3(Mg, Fe)_2SiO_4} + \underset{\text{(Alumina)}}{Al_2O_3} + \underset{\text{(Water)}}{4H_2O} - \underset{\substack{\text{(Iron and}\\ \text{Magnesia)}}}{(Mg, Fe)O} = \underset{\text{(Clinochlore).}}{H_8(Mg, Fe)_5Al_2Si_3O_{18}}$$

Slight alterations in the above equation would suffice for the production of all other species of the chlorite group. The process of alteration to chlorite throughout the mass is regarded as closely allied to that which has produced the chlorite "veins" that almost universally border the peridotite masses in this region. In the latter case, the evidence of dynamic action, causing movement between the peridotites and the adjacent gneisses, is abundant, and the transfer of alumina by solutions circulating along these planes can be well understood. Let these dynamic agencies affect the structure of the peridotite, however, and the same supplies of alumina have access to all parts of the rock; the process of chloritization may then proceed in greater or less degree throughout the mass. That such dynamic action has occurred in dunites altering in this way, is usually attested by the highly developed pinacoidal cleavage of the olivine, and the more or less distinctly schistose arrangement of the resulting chlorite. The final product is in most cases a chlorite-schist.

Examples of this mode of alteration are found in the vicinity of Shooting Creek, in Clay County (see p. 71), and in portions of the Webster area, three-fourths mile south of Addie (p. 93).

In peridotites carrying a high percentage of alumina, as in the Buck Creek amphibole-peridotites (p. 75), chloritization is frequently the normal process of alteration, and this has produced extensive masses of chlorite rock on Little Buck Creek and elsewhere.

Doubtless many of the chlorite-schists throughout the southern Appalachians are the results of similar alterations of peridotites, although many others have been produced also by the chloritization of amphibolites (see p. 160).

AMPHIBOLIZATION.

So far as observed the method of alteration described from some localities, whereby needles of amphibole are developed around the olivine grains at right angles to the surfaces and penetrating inward, does not occur in the peridotites of North Carolina. Alteration into amphibole is, however, very widespread in these rocks, particularly in the dunites, but it has not heretofore been clearly recognized. Dr. Julien [10] described a horneblendic mode of alteration, but failed to distinguish the original amphibole-peridotites from those containing secondary amphibole.

In the beginning of this alteration, as seen in much of the dunite at Corundum Hill, minute spicules, or fine needle-like prisms of colorless amphibole are found here and there throughout the mass. These are generally visible to the unaided eye, even when excedingly minute, on account of their great elongation and the glistening reflections they show on a fresh fracture of the rock. Unlike the alteration to serpentine and talc, which is usually confined to the surfaces and cracks of the olivine grains, this process seems to be entirely independent of pre-existing structures of the rock. The straight, slender needles of amphibole almost invariably penetrate certain grains of olivine as a sheer mechanical necessity. With the proportions attained even by the smallest they could seldom be confined to the irregular interstices and cracks of the olivine without considerable bending; and they are entirely too long in most cases to be accommodated in the cleavage cracks of a single individual. Consequently they are found penetrating the grains of olivine in every direction, entirely without regard to cracks or cleavage. This characteristic is shown in the photomicrographs (Pl. XL, fig. 2, and Pl. XLII, fig. 6).

As already described (p. 88) this secondary amphibole is colorless, and either orthorhombic ($\mathfrak{c} = c$) or monoclinic ($\mathfrak{c} \wedge c = 16°$ to $18°$). Several specimens containing considerable amounts of this secondary amphibole failed to show any trace of calcium with the ammonium oxalate test. These properties, together with their optical character, determine these two as anthophyllite and cummingtonite (amphibole-anthophyllite), respectively. Anthophyllite and cummingtonite are chemically similar minerals, both being metasilicates of magnesium and iron, as expressed by the formula, $(Mg, Fe)SiO_3$. The transformation of the orthosilicate, olivine, into this metasilicate involves the removal of magnesia and iron, and may be represented by the following equation:

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[10] Proc. Boston Soc. Nat. Hist., Vol. XXII, 1882, p. 141.

$$\underset{\text{(Olivine)}}{(Mg, Fe)_2SiO_4} - \underset{\substack{\text{(Iron and}\\\text{Magnesia)}}}{(Mg, Fe)O} = \underset{\substack{\text{(Cummingtonite or}\\\text{Anthophyllite).}}}{(Mg, Fe)SiO_3}$$

Where enstatite is present in the rock, as in harzburgite, the needles of secondary amphibole penetrate this mineral, as well as the olivine, in all directions. Since the amphibole has the same chemical composition as the enstatite, the alteration in such cases is purely physical, and is known as paramorphism. Amphibolization has not been observed in the amphibole-peridotites, nor in the presence of original hornblendic minerals in any of the peridotites.

All stages of the process are found, from the slightest beginnings to those in which the amphibole entirely replaces the original olivine, forming a light-colored amphibolite in which the slender individuals are crossed and interlocked in the greatest confusion. Portions of such masses have been locally sheared, producing an amphibole-schist. In addition to the Corundum Hill locality, already referred to, where this process does not attain an advanced stage of development, it is found highly developed in some of the Sapphire localities, and more or less extensively in great numbers of places throughout the region.

Alteration to amphibole has been observed in peridotites in many cases where secondary hydrous minerals, such as talc, serpentine, and chlorite, have not been developed, or have been formed to only a slight extent. This is particularly noticeable in some of the Sapphire rocks, which, in every other respect, are perfectly fresh. Although in no way connected with hydration, the presence of a solvent would seem to be necessary, since the transformation involves loss of magnesia or gain of silica. A further alteration of small portions of the secondary amphibole to talc is frequently noticeable in thin sections under the microscope.

CHAPTER V.

ORIGIN AND RELATIONS OF THE PERIDOTITES AND ASSOCIATED ROCKS.

HISTORICAL SKETCH.

Prior to 1875 but little was known of the unaltered peridotites of eastern North America, although mining operations for corundum had been begun at Corundum Hill, North Carolina, and a little desultory prospecting had been carried on over parts of the adjoining country. Hence there was but little knowledge upon which to base speculations as to the origin of the rocks. In the writings of Shepard, Genth, Logan, and others, however, the opinion is occasionally expressed or implied that the rocks are of sedimentary origin, the terms "strata" and "beds" being commonly used in reference to them. Such statements are to be regarded, of course, as simply expressions of opinion—mere impressions from very limited observation.

Since the date mentioned, theories of origin have been proposed from every conceivable point of view. Different portions of the altered and unaltered peridotite series have been studied from time to time, and have been variously pronounced unaltered sediments, metamorphic sediments, chemical deposits, metasomatic alteration products of limestones and schists, and igneous intrusions. Those who have engaged in the discussions have been divided, however, chiefly into two camps, corresponding very accurately to the old Neptunian and Plutonic schools of geology. The persistence of these opposing views throughout the closing quarter of the nineteenth century bears witness to the inherent difficulties of the problem, neither contention, apparently, being susceptible of positive proof.

The following extracts, arranged chronologically, from a number of writers who have discussed the origin of these rocks in eastern North America since 1875, serve to emphasize this remarkable variation and alternation of hypotheses.

In 1875, Mr. W. C. Kerr,[1] State Geologist of North Carolina, made the following reference to these rocks, in outlining the geology of the belt of gneisses and schists between the Blue Ridge and the Great Smoky mountains:

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[1] Rept. Geol. Survey North Carolina, Vol. I, 1875, p. 129.

> One of the most remarkable and interesting features of the geology of this belt is the line of *chrysolyte* ledges (*dunyte*), which occur along the median zone of it, outcropping in massive dikes, which form rough, jagged hills at intervals of half a score of miles, more or less, from the Rich Mountains of Watauga through Mitchell, and the intervening counties to Clay. Some of these ledges are nearly a mile long and several hundred yards wide. They are not in line with one another, but are scattered over a zone 10 to 20 miles in breadth. It is worthy to be noted that they occur in the middle zone, where the rocks are most disturbed and irregular in position; that they are associated with the most massive outcrops of hornblendic rocks,—syenites, schists and actinolyte rocks, and with heavy veins of coarse porphyroidal granite, and that they thus claim a very low horizon.
>
> The masses of chrysolyte are more or less distinctly granular, and are in fact, a chrysolytic sandstone, of a yellowish to dull, or dark olive-green color.

In an appendix to the same report, Dr. C. D. Smith[2] took the ground that these rocks are of undoubted intrusive origin, and even went so far as to attribute the metamorphism of the gneisses, in part at least, to the influence of the peridotites. He said:

> The rocks of which the main mass of this part of the Blue Ridge is composed, bear very little evidence of being disturbed since the upheaval.
>
> There is, however, a zone of gneissic rocks on the northwest side of the ridge, which has been much disturbed since the main mass was folded up. . . . Along the entire length of this zone from Cane creek, in Mitchell County, to Choeestoee, in Union County, Georgia, and perhaps still further south, there is a system of dike fissures through which, at intervals, chrysolite and serpentine have been protruded. The gneiss, which encloses these chrysolite and serpentine beds, is somewhat peculiar and deserves a more special description. It bears evidence of having been much affected by heat from the dike fissures which traverse it. It is consequently hard and crystalline in a high degree. . . .
>
> The chrysolite bears decided marks of its igneous origin. Its general crystalline texture, together with disseminated octahedral crystals of magnetite and chrome iron, speak of its igneous origin. It is a laminated rock, but the strike of its laminæ seldom conforms to the strike of the enclosing rocks. It appears to have been protruded or lifted through the fissures and laid at varying angles across the enclosing gneiss. It cannot, therefore, be regarded as a regular interfoliation, nor as an intercalation with the enclosing beds. It differs from them, as already stated, in its strike, and generally in its inclination. These facts all point to it as an igneous rock.

In 1875 also, Dr. F. A. Genth,[3] in a report on the mineralogy of Pennsylvania, expressed the belief that the "whole chromiferous serpentine range results from the alteration of chrysolite," a view that had received abundant corroboration in other parts of the world. He also noted the frequent occurrence of serpentine in association with pyroxenites, the latter sometimes bearing olivine.

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[2] Loc. cit., Appendix, pp. 91-93.

[3] Second Geol. Survey Pennsylvania, B, 1875, pp. 113-118.

In 1878 Dr. R. W. Raymond[4] called in question the correctness of this view of the nature of the peridotites, as follows:

> These are called in the state geological report dikes of chrysolite or dunite. . . . . I should not be surprised if future careful study of all the localities should show these chrysolite beds to be intercalated members of the formation in which they occur.

In the same year Dr. Clarence King,[5] in a discussion of the "Genesis of granite and crystalline schists," took up the question of the origin of serpentine and the chrysolitic rocks. He said:

> The discovery in Appalachian schists of great bodies of chrysolitic formation, making an integral part of the crystalline schists, is sufficient answer to the question, Whence came the anhydrous magnesian silicate out of which to make the pseudomorphous serpentine?
>
> Without attempting to examine the validity of Hunt's claim that the early magnesian silicates are chemical precipitates from the acid ocean of their period, I see no reason to seek for a different origin for the magnesian silicates from that of the comoner aluminous minerals. Olivine-bearing rocks are among the oldest irruptive bodies; why may not olivine sands, like those now seen on the shores of the Hawaiian Islands, have been then as now accumulated by the mechanical separation of sea currents and subsequently buried by rushes of feldspathic and quartz sands? Be that as it may, the whole tendency of microscopic research is to prove that the hydrous magnesian silicates are plainly pseudomorphic after anhydrous forms, and the problem of genesis, as Hunt very justly remarks in this connection, is, Whence the anhydrous ones? There is little present necessity, it seems to me, for the invocation of aqueous precipitates, when the sea bottom and shores of to-day offer such varied chemical materials which are so obviously detrital.
>
> From these considerations, so far as the gneisses and crystalline schists are concerned, I am led to give in a complete adhesion to the hypothesis of diagenesis for the anhydrous silicates and of subsequent pseudomorphism for the hydrous magnesian rocks. My views approximate closely to those of Dana, and, if I rightly comprehend him, of Gümbel, rejecting on the one hand the Plutonic hypothesis of Naumann and his followers, and on the other the all but forgotten theory of direct crystallization from solution, as advanced by Delabeche [p. 117].

In 1879 Dr. T. Sterry Hunt[6] made the following specific reference to the peridotites of North Carolina, in describing the Montalban series of the Primary or Crystalline rocks:

[4] Trans. Am. Inst. Min. Engineers, Vol. VII, 1878, p. 83.

[5] Geol. Exploration 40th Parallel, Pt. I, 1878, pp. 112-121.

[6] Macfarlane's Geol. Railway Guide, 1879, p. 13.

> Noticeable among the basic members of the terrane, is the granular olivine or chrysolite rock, which, often accompanied by enstatite, and by serpentine, appears to be interstratified in the micaceous and hornblendic schists of the Montalban, in North Carolina and in Georgia.

In the same year Dr. Hunt's well-known views were more fully set forth in a paper read before the American Association for the Advancement of Science, on "The history of some pre-Cambrian rocks in America and Europe."[7] His summary is quoted here:

> In opposition to both of these (neptunean and plutonist schools) are the views taught for the last twenty years by the writer, and now accepted by many geologists, which may be thus defined:
>
> 1st. All gneisses, petrosilexes, hornblendic and micaceous schists, olivines, serpentines, and in short, all silicated crystalline stratified rocks are of neptunean origin, and are not primarily due to metamorphosis or metasomatosis either of ordinary aqueous sediments or of volcanic materials.
>
> 2d. The chemical and mechanical conditions under which these rocks were deposited and crystallized, whether in shallow waters, or in abysmal depths (where pressure greatly influences chemical affinities), have not been reproduced to any great extent since the begining of Paleozoic times.
>
> 3d. The eruptive rocks, or at least a large part of them, are softened and displaced portions of these ancient neptunean rocks, of which they retain many of the mineralogical and lithological characters.

In 1880 Prof. W. O. Crosby[8] described the serpentine of Lynnfield, Massachusetts, as an altered limestone. As this rock occurs in relations very similar to many of the unaltered peridotites of eastern North America, this view is given as bearing upon the general question of origin of the whole series. He said:

> The limestone in Lynnfield is far more serpentinic than that in Newbury. The serpentine appears to be everywhere present and abundant; in fact, Prof. Hitchcock did not seem to regard this rock as limestone at all, but described it under the head of serpentine; and a specimen analyzed by Dr. C. T. Jackson contained no calcic carbonate. There is no doubt, however, that the rock as a whole is a very serpentinic limestone, for it is distinctly stratified; and a glance at the map will show its intimate relations with the regular stratified group on the west.

In the year 1882 Dr. A. A. Julien, in a paper on "The Dunyte-beds of North Carolina,"[9] presents the conclusion that these rocks are of sedimentary origin, the accumulations of olivine sands, "doubtless from some ancient terranc, perhaps of lower Laurentian age, of chrysolitic lavas or gabbros, now worn down and buried beneath the later sediments, beyond our view." After explaining the usual elliptical and lenticular forms of outcrop as due to the fact that the beds are always highly tilted and hence always seen in cross-section, he presents the following evidence as showing their sedimentary origin:

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[7] Am. Jour. Sci., 3d ser., Vol. XIX, 1880, pp. 268-283. Read before A. A. A. S. Sept. 1, 1879.

[8] Contributions to the geology of eastern Massachusetts; Boston Society of Nat. Hist., Occasional Papers, III, 1880, p. 115.

[9] Proc. Boston Soc. Nat. Hist., Vol. XXII, 1882, pp. 141-149.

> The rock always possesses a marked slaty lamination, exactly like that of the slaty hornblende-gneisses surrounding it, the distinct laminæ usually varying from one-half to 1 cm. That these laminæ really indicate the bedding planes of a mechanical sediment, and not the characteristics of a chemical deposit, is shown by three facts:
>
> 1st. On microscopic examination of thin sections, transverse to the lamination, there is always shown an alternation of coarser and finer irregular veins, the certain mark of a sorting out of sediments deposited in water.
>
> 2d. The chromite grains are not only dispersed through the dunyte, in exactly the same way as those of iron ore through the siliceous sands on a sea-coast; but are often concentrated in laminæ about a centimeter in thickness, alternating with those of olivine, or even in coarser layers of a chromite breccia, with kammererite-scales acting as a cement. These coarser layers are often spoken of as "veins," but always lie in the plane of stratification, and often show the sorting process among their own grains.
>
> 3d. At a few localities, near the margin of a huge mass of dunyte, this rock is found to be interbedded with the hornblende-gneiss, in layers 1 to 6 meters in thickness. This was shown by a cross-section of the beds on the north side of the dunyte deposit at the Jenks mine, near Franklin, in Macon County. Although the dunyte is thus enclosed in, or interbedded with the hornblende-gneiss, the latter was never observed to be enveloped by the dunyte.
>
> All its characteristics . . . are simply those of a chrysolite-sandstone, which, wherever unaltered, and thus without accessory fibrous constituents as a cement or binding material, is pulverulent and friable.

A sedimentary theory of the origin of the serpentines was adopted by the Second Geological Survey of Pennsylvania, the theory of igneous origin held by Rogers, State Geologist of the First Pennsylvania Survey, being rejected. In 1883 Prof. J. P. Lesley[10] wrote:

> Sterry Hunt ascribes the serpentine beds in crystaline schists to an original deposit in sea water. In fact the form of serpentine strata often proves this. In Banffshire, Scotland, thick lenticular beds of serpentine lie among the crystalline schists and limestone, and are crumpled and folded with them as an original element in the general stratification. The same thing occurs in Northampton County, Pennsylvania, and elsewhere.
>
> It is possible that none of the serpentines of southern Pennsylvania are in any respect eruptive or volcanic; but that all of them are original sedimentary magnesian rocks subsequently changed more or less into the simple silicate of magnesia, by percolating waters; assisted in some places, it may be, by outbursts of volcanic traps, and perhaps eruptive granitoid rocks.

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[10] Second Geol. Survey Pennsylvania, C4, 1883, pp. 353, 354.

In 1883, in a paper discussing the structural and chemical relation of the northern serpentine belt in Chester County, Pennsylvania, Dr. Persifor Frazer[11] reached the following conclusion:

> These results seem to lend a high degree of probability to the theory that at least this belt of serpentine is a metasomatized product of a layer or layers of the hydro-mica schists in contact with which it lies, and with which its relations are otherwise abundantly made out by very different processes of comparison, viz., stratigraphically, geographically, and chemically.

In 1884 Dr. M. E. Wadsworth[12] took issue with Dr. Julien as to the sedimentary origin of the North Carolina dunites. After giving a summary of the evidence presented by Dr. Julien, he wrote:

> From the above Dr. Julien draws the conclusion that this dunite is neither of chemical nor of eruptive origin; that is, it is an olivine sandstone. The chief defect in Dr. Julien's reasoning is, that all the evidence which he gives in support of this view could exist equally well if the rock had some entirely different origin. . . .
>
> The present writer's microscopic study of the North Carolina dunite showed him that the rock he was studying, even when destitute of some cementing material, was not friable and pulverulent, while the sections to his mind presented characters belonging to eruptive rocks only. The olivine grains are separated by fine fissures, but every irregularity in the outline of one is matched by a corresponding irregularity in the adjacent bounding grains. If these grains had been water- or wind-worn olivine sand, no such matching of the parts would have been possible. . . . The olivine rock now under consideration has absolutely no interstitial spaces and no binding material, but the grains are fissured and separated the same as the adjacent portions are separated in cracked and fissured glass. From this the conclusion naturally follows that such structure indicates that these olivine grains were formed by the cracking of olivine mass during the process of solidification, crystallization, and cooling; that is, from an eruptive mass.
>
> Further, individuals of olivine are seen in polarized light to be made up of a number of distinct grains, as much separated from each other as the distinct individual grains are elsewhere in the section. This is a natural and common occurrence in an eruptive rock, but in a sedimentary one the parts ought to be scattered. Many of these individuals, too, are long, wedge-shaped masses with sharply pointed ends. If they had been water- or wind-worn grains they ought to have had these sharp edges worn, rounded, and broken. These long, lenticular, fissured individuals are also arranged at every angle to one another, when, if the rock were sedimentary, they ought to lie nearly parallel and on their sides.

Also in 1884 Dr. A. R. C. Selwyn,[13] Director of the Geological and

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[11] Trans. Am. Inst. Min. Engineers, Vol. XII, 1883, p. 355.

[12] "Olivine rocks of North Carolina," Science, Vol. III, 1884, pp. 486, 487.

[13] Descriptive Sketch of the Physical Geography and Geology of the Dominion of Canada, Montreal, 1884, p. 13.

Natural History Survey of Canada, described the "pre-Cambrian subcrystalline rocks" of Quebec as consisting of "hydromica slates, quartzites, crystalline dolomites, diabase, gabbro, olivinite, serpentine, and volcanic agglomerates, the lowest beds of the axis being micaceous and granitoid gneisses. Many of these volcanic agglomerates and diabases are now serpentines . . . ."

In a "Report on Explorations and Surveys in the interior of the Gaspé Peninsula, 1883," published in 1885, Mr. A. P. Low[14] described the peridotites and serpentines and associated schistose rocks, regarding the former as igneous intrusives. He says:

> Along the South Branch of the Ste. Anne River, on the south side of the great mass of serpentine and olivine which crosses the river, dark hornblende-schists and green chloritic slates were seen, corresponding to those on the north side, and probably identical with them, thus showing that the great mass of serpentine which composes Mount Albert has thrust up the beds of this system, forming a great anticlinal with reversed dip. The top of this anticlinal having been denuded off, leaves beds of the same rocks on either side of the serpentine; those on the north side apparently dipping under the mass, while those on the south appear to lie upon it [pp. 18, 19F].
>
> Banded structure is distinctly seen among the serpentines on the mountain, but the direction of the strike of the beds is not continuous, nor parallel to that of the surrounding stratified schists, and is supposed to be due to flow structure, as the olivine is undoubtedly of igneous origin [p. 20F].

In another portion of the same report, Mr. R. W. Ells[15] describes another serpentine area in the Gaspé and takes the same view as to its probable igneous origin. He says:

> Although the serpentines of this area have generally been regarded as an integral portion of the metamorphic series and contemporaneous in age, there are indications at several places which point to an eruptive origin. The position of the eastern or Mount Albert mass in particular, breaking, as it does, apparently across strata of pre-Cambrian and Silurian age, gives it the aspect of an immense dyke, while the exposure noted as crossing the Salmon Branch, much of which is of peculiar character, is also like an intrusive rock.

In 1886, in a study of the gabbros and associated hornblende rocks in the neighborhood of Baltimore, Dr. G. H. Williams[16] also described the serpentines and peridotites of eastern Maryland. The following passage is quoted from the summary:

> Chapter V contains descriptions of the third or olivinitic rock type, which is abundantly associated with the gabbro and gabbro-diorite. These rocks are

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[14] Geol. Survey Canada, Rept. of Progress, 1882-83-84, pp. 1-21F, 1885.

[15] Geol. Survey Canada, Rep. of Progress, 1882-3-4, p. 32E.

[16] Bull. U. S. Geol. Survey No. 28, 1886, p. 12.

> younger than the gabbro, since they break through it in the form of dikes. . . . As far as could be observed the olivine seems always to form serpentine, and the pyroxene (no matter what be its form), hornblende. This latter mineral often suffers a further alteration to talc, its lime separating out in the form of calcite. In this manner the hornblende serpentines, like those of the Bare Hills, have been derived from original eruptive aggregates of olivine and bronzite, similar in character to many rocks which are still to be found near them in a quite unaltered condition.

In the same year, Mr. J. S. Diller[17] described the peridotite dikes which cut the Carboniferous strata of Elliott County, Kentucky. The results of the investigation of this rock are more fully set forth in a bulletin[18] issued the following year. The following extract is from the summary in the latter publication:

> The peridotite is associated with nearly horizontal Carboniferous sandstones and shales, from which it differs widely in chemical and mineralogical constitution. It not only includes numerous fragments, but has greatly indurated the shale near the contact and has itself suffered endomorphic effects in the production of a sphærolitic structure corresponding to that of variolites. These facts clearly indicate that the peridotite is eruptive and render its occurrence of much importance, for it so rarely happens that peridotites are found under such circumstances that their eruptive character can be fully established.

In 1887 Dr. G. H. Williams[19] also described an occurrence of peridotite intersecting Paleozoic sediments (Onondaga salt-group) at Syracuse, New York.

In the same year Dr. Frederic D. Chester[20] described the "State line serpentine" along the boundary of Pennsylvania and Maryland, which he found to be chiefly an altered pyroxenite, a bronzite-diallage rock, sometimes containing olivine.

In 1887 Mr. T. M. Chatard,[21] discussing "The gneiss-dunyte contacts of Corundum Hill, North Carolina, in relation to the origin of corundum," makes the following reference to the origin of the dunite (p. 47):

> The origin of the dunyte, whether igneous or sedimentary, and, if the latter, whether mechanical or chemical, is a disputed question . . . . and upon this point I am not able to give any further information of value. Leaving out the question of the origin of the dunyte, it appears very much like a dike or dike series, portions of which have been forced into the adjacent country rock without completely severing the connection with the main mass.

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[17] Am. Jour. Sci., 3d ser., Vol. XXXII, 1886, pp. 121-125.

[18] Bull. U. S. Geol. Survey No. 38, 1887, p. 29.

[19] Am. Jour. Sci., 3d ser., Vol. XXXIV, 1887, pp. 137-145.

[20] Ann. Rept. Second Geol. Surv. Pennsylvania, 1887, pp. 93-105.

[21] Bull. U. S. Geol. Survey No. 42, 1887, pp. 45-63.

In 1890 Mr. Theodore D. Rand[22] described many of the serpentines of eastern Pennsylvania, and made the following reference to their origin:

> One prominent feature of most of the Pennsylvania outcrops above described is the abruptness of their appearance and disappearance, in this respect resembling far more plutonic masses than interstratified beds or synclinal basins. . . . Nevertheless, the position of the serpentine belts close to the Laurentian on the one side, and with mica and hornblende schists on the other, seems to forbid our regarding them as intrusive rocks. . . . The theory of interbedding . . . . seems the only one tenable.

In 1894 Mr. Francis P. King,[23] in his report on the corundum deposits of Georgia, referred to the nature of the peridotites as follows:

> These form igneous intrusions along the stratification lines of the holocrystalline rocks, the gneiss and schist showing by existing characteristics that they were distended prior to the final folding of this region.

In 1895 Prof. J. Volney Lewis[24] discussed at some length the origin of the peridotites of the southern Appalachians, presenting evidence from both field investigations and microscopic study, indicating that they are igneous intrusions. The conclusion is stated as follows (p. 35):

> Hence I am led to the conclusion that no theory of sedimentary origin can adequately account for existing conditions, and that these olivine rocks are now practically in the state in which they originally solidified from the molten magma.

In 1897 Dr. Wm. B. Clark,[25] State Geologist of Maryland, in an outline of the geology of the State, made the following reference to the character of the peridotites and related rocks:

> The rocks composing the holocrystalline portion of the Piedmont Plateau in Maryland, are petrographically divisible into seven distinct types. Four of these are of undoubtedly eruptive origin and may be designated according to their chemical and mineralogical composition as diorite, gabbro, peridotite or pyroxenite, and granite. The remaining types through which the eruptive rocks have broken—gneiss, marble, and quartz-schist—are completely crystalline, and therefore exhibit no certain trace of clastic structure, although it seems highly probable that they were of sedimentary origin. . . .
>
> The second type of eruptive rock which penetrates the gneiss complex near Baltimore is younger than the gabbro, but it is genetically closely allied to it. These two types are connected by many intermediate varieties; and the more basic rocks, which break through the gabbros as well as through the gneiss, may be regarded as having resulted from a gabbro-magma which had become relatively poor in alumina, or in alumina and silica.

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[22] Proc. Acad. Nat. Sci. Phila., March, 1890, pp. 76-123.

[23] Bulletin Geol. Survey Georgia, No. 2, 1894.

[24] Jour. Elisha Mitchell Sci. Soc., Vol. XII, pt. 2, 1895, pp. 24-37.

[25] Maryland Geological Survey, Vol. 1, 1897, pp. 162, 165.

In 1898 Dr. Joseph Hyde Pratt,[26] discussing the origin of the corundum associated with the peridotites in North Carolina, referred to the conclusion of Prof. Lewis, quoted above, and further added:

> The author has examined nearly all the known outcrops of these rocks in this State during the past two years, in connection with his work on the corundum deposits. The result of these examinations has led to the same conclusion regarding the origin of the peridotites. . . .

In the same year Prof. B. K. Emerson[27] published an exhaustive report on the Chester amphibolites and serpentines of Massachusetts, in which their nature and origin are discussed at length, with the following conclusion:

> I conclude, then, that the Chester series represents an eastward expansion of the limestones of the Silurian sea which deposited the Stockbridge and Bellowspipe limestone in Berkshire, and that it may be tentatively paralleled with the later bed. Some very basic igneous rocks may have been associated with this, its shoreward, extension, and along its central part its upper surface was, at a later time, replaced locally by limonite [p. 155].

Prof. Emerson also considers the amphibolic members of the crystalline schists east of the Connecticut valley as the equivalents of the Chester amphibolites.

For the saxonite and serpentine of Pelham, Shutesbury, and New Salem, however, Professor Emerson finds quite a different origin. Describing the typical occurrence at the Pelham asbestos quarry, he says:

> This is a great lens or short dike—probably an old volcanic core—of the highly basic igneous rock saxonite, in the highly acid conglomerate-gneiss; and during the strong metamorphism which has transformed the conglomerate into a gneiss, the saxonite has been largely changed into anthophyllite, and, what is of higher interest, a broad selvage—a " reaction rim " on a grand scale—has formed by the mutual influence of the basic core and the acid surrounding. This selvage consists largely of minerals containing little or no silica—apatite, corundum, magnetite, tourmaline, anorthite, and biotite. It wraps around the saxonite with great irregularity, often folding deeply into its mass [pp. 47, 48].

In 1900 Mr. Theodore D. Rand[28] again discussed the geology of southeastern Pennsylvania, and revised his former views as to the origin and character of the serpentines, arriving at the conclusion that " there seems to be no doubt that all the serpentines in southeast Pennsylvania are altered igneous rocks, either pyroxenites or peridotites " (p. 305). This conclusion is stated in a somewhat more guarded manner in the following passage (pp. 316-317):

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[26] Am. Jour. Sci., 4th ser., Vol. VI, 1898, pp. 49-65.

[27] U. S. Geological Survey Monographs, Vol. XXIX, 1898, pp. 78-155.

[28] Proc. Acad. Nat. Sci. Philadelphia, Feb. 1900, pp. 303-318.

> Whatever doubt there has been as to the origin of the serpentines, petrographic studies seem to prove that almost, if not quite, all are derived from the alteration of a basic igneous rock, peridotite, amphibolite, or pyroxenite, except in the comparatively few occurrences in limestone. In several of the outcrops in this region the unaltered mother-rock may be found in all stages of alteration, and this macroscopically. This may be seen at Rose's quarry, opposite Lafayette on the Schuylkill, and to the westward, and on the same belt near Darby creek and in Marple; near the corundum mines in Newlin, Chester County, and at Radnor. At most localities the original rock seems to have been an orthorhombic pyroxene, enstatite or bronzite. In the neighborhood of Glen Riddle, southwest of Media, some of the serpentine is after actinolite.

In 1901 Mr. D. H. Newlands[28a] published a description of "The Serpentine of Manhattan Island and Vicinity, and their accompanying minerals." He arrived at the following conclusion in regard to the origin of these rocks:

> A number of considerations . . . . indicate that the original rocks were of igneous character and allied to the pyroxenites and peridotites, rather than that they were impure limestones, as has been believed by some geologists.

In 1901 Mr. Arthur Keith,[29] of the U. S. Geological Survey, ascribed to the soapstone and related rocks of the Washington quadrangle (D. C.-Md.-Va.) an eruptive origin, as follows:

> In this district small areas of highly metamorphosed rocks—soapstone and talcose schist—occur, which are probably derived from pyroxenite and peridotite. Similar rocks of like origin occur in other areas of the Piedmont Plateau. None of them form large bodies and their outcrops have a lenticular shape. Their close association with the eruptive rocks, especially the basic ones, suggests a like nature and age for them all.
>
> Soapstone masses are common around the gabbro areas, and many intermediate rocks indicate original transitional forms between the two types.

In 1902 Dr. F. J. H. Merrill,[30] State Geologist of New York, described the igneous rocks intrusive in the gneisses and schists of New York and vicinity. These include, besides granites and diorites, "basic dikes, including amphibolites and pyroxenites, and serpentine derived from basic intrusives."

> At New Rochelle the serpentine has been derived from the alteration of rocks consisting of bronzite, hornblende, and actinolite, remnants of which may still be found. The area on Manhattan Island is evidently of similar origin.
>
> On Staten Island traces of olivine and actinolite have been found in the

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[28a] School of Min. Quart., Vol. 22, 1901, pp. 307-317, 399-410.

[29] U. S. Geol. Survey Folio No. 70, 1901, p. 3.

[30] U. S. Geol. Survey Folio No. 83, 1902, p. 5.

serpentine, which suggests its derivation. At Hoboken no traces of the original mineral have been found, but its origin is evidently analogous to that of the other masses.

In 1902 Dr. F. Bascom [31] described the amphibolite, serpentine, and soapstone of Cecil County, Maryland, as igneous intrusions (metapyroxenites and metaperidotites) in the gneisses and gabbros. Under the head of "Igneous Intrusives" she said:

> The mica-gneiss constitutes the only sedimentary formation among the crystallines of Cecil County. That the other members of the crystalline belt are igneous material, more or less metamorphosed, will become clear as the discussion proceeds. The igneous rocks follow closely the strike of the sedimentary formation.

In 1903 Mr. Arthur Keith [32] also described the dunite, serpentine, soapstone, etc., of the Cranberry quadrangle (N. C.-Tenn.) as igneous intrusives that "break through and across the beds of Roan gneiss."

Also in 1903 Dr. A. A. Julien [33] discussed at length the "Genesis of the Amphibole-schists and Serpentines of Manhattan Island, New York," and arrived at the conclusion that the genesis of the serpentine "is interwoven with that of the amphibole-schists," and that both are the results of alteration of basic igneous intrusions.

In 1904 Dr. E. B. Mathews,[34] in discussing "The Structure of the Piedmont Plateau as shown in Maryland," wrote as follows in regard to the nature of these rocks:

> Throughout the Piedmont area under discussion have been recognized numerous igneous rocks, now more or less metamorphosed, which are apparently intruded into all of the rocks as old as the mica-schists. Among the types found are granites and granite-gneisses, diorites and metadiorites, gabbros and metagabbros, peridotites, pyroxenites and serpentines, metarhyolites, and metabasalts.

Many others might be added, but these are representative and show the strong trend of modern thought toward the theory of igneous origin.

SUMMARY OF FACTS AND THEIR INTERPRETATION.

As pointed out in the historical sketch above, many of the facts presented in this report and in Bulletin No. 11 have been briefly discussed in previous publications [35] in their bearing upon the origin of the peridotites and associated rocks. The conclusion that these rocks are of intrusive igneous origin has been still further confirmed by subsequent studies. It seems desirable, therefore, that a summary of facts bearing on this subject, and the interpretations assigned to them, should be set forth here. For this purpose the data may be conveniently arranged under five heads, as follows:

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[31] Maryland Geol. Survey, Cecil County, 1902. pp. 90-103.

[32] U. S. Geol. Survey Folio No. 90, 1903, p. 3.

[33] Bull. Geol. Soc. of America, Vol. 14, 1903, pp. 421-494.

[34] Am. Jour. Science, Vol. XVII, 1904, p. 145.

[35] Jour. Elisha Mitchell Sci. Soc., Vol. XII, 1895, Part. 2, pp. 24-37; Am. Jour. Sci., 4th ser., Vol. VI, 1898, pp. 49-51.

1. Mineralogical characters.
2. Microscopic characters.
3. Gross structures.
4. Modes of occurrence.
5. Relations to the gneisses and schists.

MINERALOGICAL CHARACTERS.

The dunites and all varieties of associated rocks throughout the peridotite belt of eastern North America, in the fresh anhydrous condition, conforms closely in mineralogical constitution to well-recognized types of igneous rocks. The predominant olivine in all the peridotites possesses the well-known allotriomorphic granular structure which characterizes the principal constituents of Plutonic igneous rocks as a class. Chromite, the most basic constituent, is the only one frequently showing crystal boundaries; and this, too, fully conforms to the principles of crystallization found to prevail in the slow consolidation of a molten magma.

In some respects the mineralogical constitution of these rocks is also indicative of igneous origin. Chromite, and more rarely picotite, is a constant and characteristic accessory in all of the peridotites. Sometimes it forms masses of considerable size, and has been mined more or less in various parts of the belt; but in all cases observed, whether it exists in the larger masses or not, it is found more or less plentifully scattered through the mass of the rock in small octahedral crystals and irregular grains. The universal occurrence of this mineral, which is unknown in crystalline rocks of metamorphic origin, is regarded as specially significant. Almost equally striking is the great scarcity of carbonates in these rocks. They do occur in small veins and irregular masses in a number of places, but always in very small amount. In the great majority of outcrops, no trace of carbonates has been observed. Where found at all they are invariably associated with talc, chlorite, serpentine, and other secondary minerals, such minerals usually greatly predominating. Hence there can be no reasonable doubt that the small quantities of carbonates that do occur are of secondary origin, and in no case to be regarded as survivals of a former condition of these rocks.

MICROSCOPIC CHARACTERS.

All of the peridotites in fresh or only slightly altered condition exhibit in thin sections a thoroughly crystalline, granular structure, usually ranging in texture from medium-fine to coarse. However, olivine grains one-half inch to 1 inch in diameter are not infrequently seen in some of the coarser varieties; and in some localities the olivines attain the extraordinary dimensions of 4 to 6 inches in diameter, as near Balsam Gap, Jackson County, and on South Toe River, Mitchell County. The typical, granular, allotriomorphic structure of the fresher peridotites is abundantly illustrated in the petrographic descriptions in Chapter III, with the accompanying plates. In thin section the predominating olivine is found to be invariably angular in outline, rarely possessing crystal form; and the grains fit perfectly together without interstitial spaces or cementing material of any kind (see Pl. XLI, figs. 1, 2). In the first stages of alteration the grains are separated by thin films of serpentine, but the irregularities of adjacent grains still remain perfect counterparts. Only in the more advanced stages of serpentinization do the corners become rounded and the intervening films of serpentine assume the appearance of an interstitial cement in sandstones. Sometimes in the serpentine derived from the complete alteration of these rocks the outlines of the angular, close-fitting grains of the original rock are still preserved in the mesh-structures of narrow reticulate bands of parallel-polarizing, fibrous serpentine, representing the first stage of alteration along the borders and fissures of the original olivine grains (Pl. XLIV, fig. 4). Similar evidence of former granular structure is sometimes preserved in the serpentines by the thin films of black oxides that are often differentiated along the borders of the grains in the early stages of alteration (Pl. XXXV, figs. 5, 6). These structures, so characteristic of igneous rocks, are not adequately accounted for by any other hypothesis than that the peridotites are themselves igneous.

In the thinly laminated varieties the microscope shows an alternation of zones of finely pulverized olivine with thin sheets of typical granular structure, in which the grains are still unbroken, fit perfectly together, and are entirely undisturbed—characters in every respect the same as observed in the massive varieties (Pl. XLI, fig. 5).

GROSS STRUCTURES.

Many of the peridotites have a pronounced laminated structure, similar to that of the enclosing gneisses. In some instances this is so highly developed as to warrant the use of the term schist in describing them

(Pl. IX, A and B). Some parts of the Webster area exhibit this structure to a marked degree, and more or less of it may be seen in great numbers of outcrops. A short distance below the surface the lamination is much less distinct, and often it is not noticeable at all at depths of a few feet; showing that, unlike the foliation of the gneisses, it is a structure that is revealed chiefly through the agency of weathering.

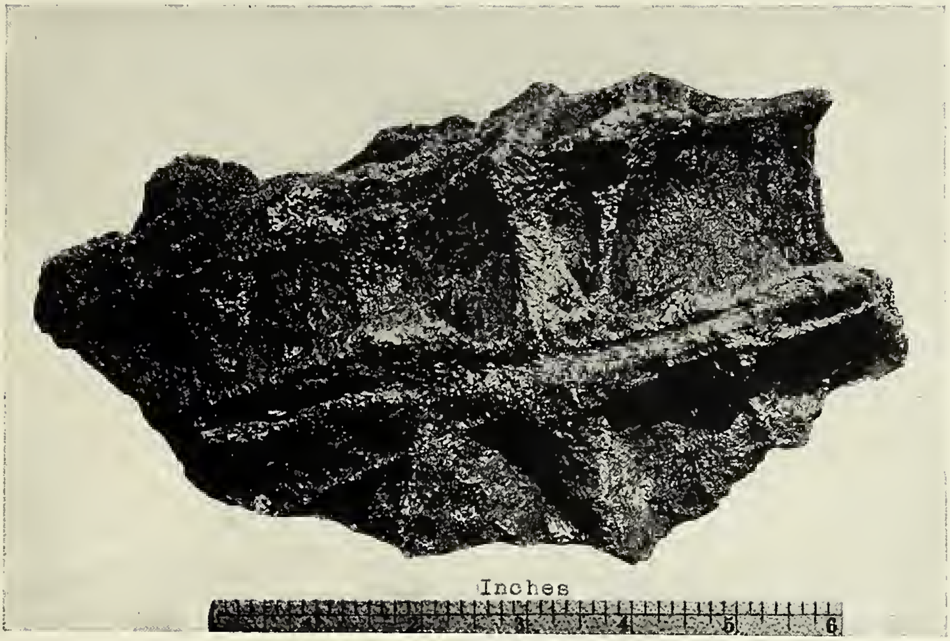
On the other hand, many outcrops are entirely without lamination, or are laminated only in part. The typical peridotite outcrops of the region may be said to consist of massive granular rock, in the main, with more or less local lamination, particularly near the borders, in the thin extremities, and in apophyses. An irregular jointing, along which weathering proceeds more rapidly, or which is made more prominent by the development of talc and other resistant minerals along its planes, is the most prominent structure in such an outcrop. Even in the masses which are more highly laminated, areas are not infrequently observed in which this structure is very feebly developed or entirely absent.

Where several types of peridotite are developed in different parts of the same mass, as at Buck Creek, where dunite, amphibole-peridotite, and troctolite occur together, the areas occupied by the different varieties are entirely irregular and without discoverable system. Lamination, when developed in such cases, passes through the mass of the rock from one type to another regardless of mineralogical variations.

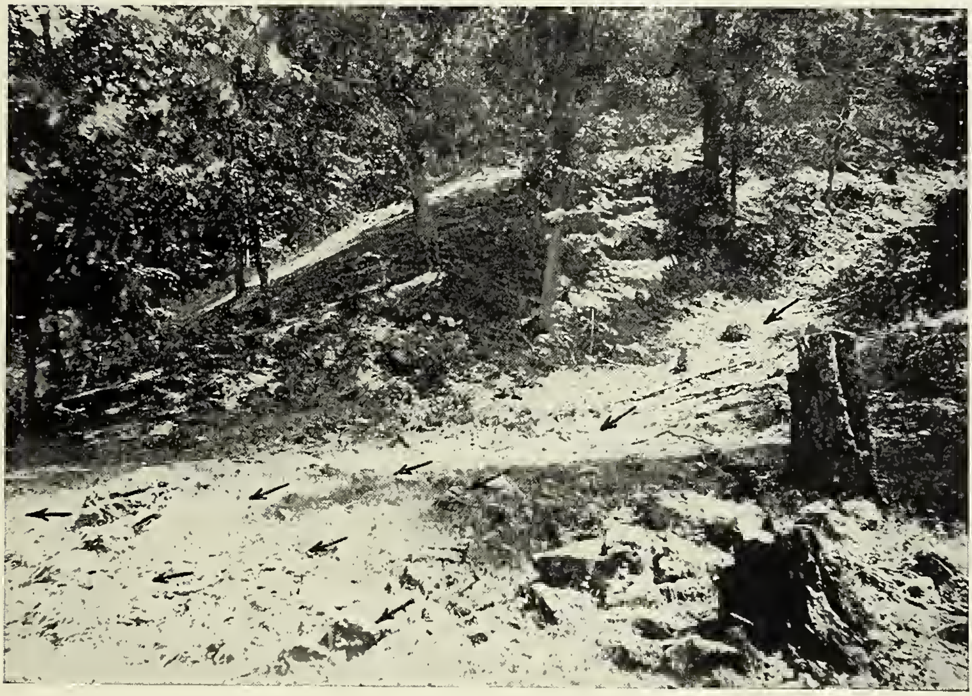
As explained above, the examination of thin sections under the microscope shows these laminated varieties to consist of an alternation of layers of pulverized olivine with others of typical, massive, granular structure. This structure, then, is believed to be intelligible only on the supposition that the rock was originally a structureless granular mass in which lamination has been induced dynamically. The relations of the mineralogical varieties and the existence of many portions of the rocks with this massive character still preserved are compatible with no other theory of origin that has been proposed.

MODES OF OCCURRENCE.

In the descriptions of the distribution of the peridotites, in Chapter II, it will be noted that, in the vast majority of cases, the outcrops are found to have lenticular or elliptical outlines, with their longer axes conforming to the direction of lamination of the enclosing gneisses. Such masses are frequently found to occur at short intervals along straight lines or in a series of parallel lines. Occassionally nearly uniform width of outcrop can be traced to relatively great length, indicating sheet-like masses. In both oval masses and sheets, however,



A, WEATHERED SURFACE OF HARZBURGITE (SAXONITE) SHOWING PROJECTING TALC VEINS. NEAR BALSAM GAP, JACKSON COUNTY.



B, LANDSLIDE IN HARZBURGITE (SAXONITE) NEAR BALSAM GAP, JACKSON COUNTY, N. C.

irregular variations sometimes occur, as illustrated on the various maps accompanying this report.

In several instances the lenticular masses are distinctly bifurcate; as at the Hamlin mine, in Macon County; on Elk Ridge, in Ashe County; and at the Asbestos mine, at Sapphire, Jackson County. In these cases the two extremities of the forked end are approximately equal in extent and similar in form. More radical departures from the compact lenticular form are found, however, in the numerous instances where narrow, finger-like, or curved and irregular apophyses branch off through the gneisses. Several examples are shown on the maps of the Buck Creek, Corundum Hill, and Webster areas; and others of various forms are described in Chapter II.

Perhaps the most significant occurrence yet observed is found in the Webster area (Pl. VIII) 5 miles northeast of Webster and one mile northwest of Addie, where peridotite entirely surrounds an area of gneiss more than one-fourth mile long and about half as wide. A dunite dike, 7 inches thick, with well-developed columnar jointing, intersects the coarse-grained harzburgite in a railroad cut 2 miles west of Balsam Gap, in Jackson County (Pl. X, A). It is difficult, if not impossible, to conceive of these modes of occurrence as the results of any other process than that of igneous intrusion.

RELATIONS TO THE GNEISSES AND SCHISTS.

In all outcrops the basic magnesian peridotites are sharply differentiated from the highly acid aluminous gneisses. Sometimes there is more or less interlamination along the borders of the peridotite masses, thin sheets of gneiss and peridotite alternating with each other for a distance of several feet, as at Webster, Shooting Creek, Corundum Hill, etc. But in all cases the types are perfectly distinct, with no tendency to the development of intermediate or transitional forms. Along the planes of contact there is always more or less development of schistose talc, chlorite or vermiculite between the adjacent rocks. These sometimes form only very thin sheets, but are more frequently from one foot to several feet in thickness, and are always clearly of secondary origin. By any process of chemical or mechanical sedimentation intermediate rock-types would most probably have been formed, at least in some cases.

The lamination of the gneisses almost invariably follows the outlines of the peridotite masses. The few instances where they have been found to meet these boundaries at a perceptible angle are quite exceptional. Such a conformity of the strike in the gneiss to the boundaries of eruptive masses which it surrounds has frequently been observed; and these relations, with only occasional exceptions, are what would be expected from the intrusion of a molten magma into a highly laminated rock.

That these rocks occupy planes of weakness in the gneisses, along which subsequent movement has taken place, is strongly suggested by the universal development of schistose secondary minerals about the borders of the peridotites. This view is still further supported by the remarkable relations between the peridotites and the system of amphibolite dikes in the Buck Creek area (Pl. V). The fidelity with which most of these intrusions follow the borders of the peridotites, both around the main mass and along the extremely attenuated apophysis, is strikingly shown on the map. Similar relations of amphibolites and peridotites are well exhibited about Elf, on Shooting Creek, in Clay County. Another evidence that movements have occurred along the planes occupied by the peridotites is the widespread development of lamination in these rocks, a structure which the microscope shows to be the result of shearing.

GENERAL PETROLOGY OF THE PERIDOTITES AND ASSOCIATED ROCKS.

In considering the relations of the various peridotites and associated basic magnesian rocks to each other, the Buck Creek area may be regarded for many reasons as typical. In no other locality in North Carolina are so many rock types found intimately associated, although, as a rule, two or more kinds occur together in the larger peridotite areas throughout the region. The variety represented at Buck Creek is so great as to include almost the whole series found in the Appalachian region, and their relations are also typical of the peridotite belt as a whole. Hence the principles deduced from a study of this locality are of wide application; and it is believed that they may be found to apply not only to western North Carolina, but to the petrology of the peridotites and their associates and derivatives throughout the crystalline areas of eastern North America.

RELATIONS OF THE BUCK CREEK ROCKS.

In the small area on top of the mountain, near the southern border of the peridotite, there are found in close proximity, dunite, amphibole-peridotite, troctolite, anorthosite, and amphibolite[36] in such relations and with such apparent transitions as strongly to suggest a genetic connection. Specimens were collected here for the purpose of determining this question, if possible, by microscopic examination. Specimens numbered B16 to B34 were thought to include transitional forms, if such occur, and thin sections from these gave the following results:

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[36] These amphibolic rocks are here referred to as original, although certainly some of them and probably many, if not all, are paramorphic derivatives of the corresponding pyroxenic rocks, and are closely analogous to the gabbro-diorites of Maryland and Delaware. For the purposes of this discussion, however, the question whether they are to be regarded as primary or secondary rocks is entirely immaterial, since only paramorphic changes are involved, and the magmatic relationships would be the same in either case.

Nos. B23 and B24 show remarkably distinct contacts of dunite and troctolite. The demarcation is everywhere distinct, as shown by the photomicrograph reproduced in Pl. XXXVIII, fig. 1. In the troctolite olivine predominates, and the feldspar has been replaced by corrosion products.

B27 and B29, on the other hand, are highly feldspathic troctolites, or olivine-anorthosites, being composed of anorthite chiefly, with corrosion products almost completely replacing the olivine. The characters of these sections are identical with those shown in Pl. XXXVIII, fig. 4. It is noteworthy that in these sections the enstatite of the corrosion mantles, which invariably lies next the olivine in the normal troctolites of this region, has been largely replaced by a colorless, monoclinic amphibole, with the properties, so far as determined, of tremolite. In many places no enstatite at all is visible, while in others granular enstatite replaces only the last central remnant of the olivine. This variation of the corrosion products is attributable to the predominance of anorthite, producing lime-bearing and possibly aluminous minerals throughout the thickness of the mantle. This hypothesis is also in accord with the fact that besides the usual large amount of green spinel intergrown with the fibrous green amphibole, there is an excess of alumina which has crystallized as corundum.

In sections B16 and B30 to B32 light green aluminous amphibole, in well-defined distinct grains, is the predominant constituent, although anorthite is abundant in some sections and rarely absent altogether. These are typical amphibolites. In some sections dark brown picotite and corundum are intergrown in numerous exceedingly irregular masses of extremely variable size. The corundum is usually pleochroic: light pink and colorless. Broad, irregular, cleavable masses of pink to ruby-red corundum, several inches in width, are not uncommon in the rock from which these specimens were taken. The small grains and larger ragged masses of highly refracting minerals in Pl. XXXIX, fig. 5, are corundum. The picotite occurs alone also, in numerous, rounded, microscopic grains; and where it occurs the adjacent hornblende grains have a brilliant grass-green color, which often extends to a distance equal to several times the diameter of the picotite.

It will scarcely be doubted that the corundiferous anorthosite described above is essentially the same as the troctolite with which it is associated, and there can be no question as to the unity of the anorthosite and the amphibolite. Typical specimens of both may frequently be taken from the same mass within a few inches of each other. Thus we have intimately associated, and apparently representing facies of the same magma, rocks possessing a wide range of physical and mineralogical characteristics; namely, dunite, amphibole-peridotite, troctolite, olivine-gabbro, amphibolite, diorite, and anorthosite (see p. 152).

With all their diversity, however, we may conceive of these rocks as essentially the products of a magnesian silicate magma containing small amounts of lime and alumina. The original undifferentiated magma was doubtless essentially a magnesia-lime-alumina silicate in which the magnesia constituent greatly predominated over the lime and alumina. Through varying degrees of differentiation and different conditions of crystallization, this magma gave rise to the types above enumerated, besides intermediate transitional forms.

By far the greater part of this original magma formed rocks consisting largely of olivine; namely, dunite, amphibole-peridotite, and troctolite, the first two greatly exceeding in amount all the other varieties. In those portions of the magma containing but little of the lime molecule anorthite crystallized in small amount and has been entirely replaced by corrosion products, as in the less feldspathic facies of the troctolites (Pl. XXXVIII, fig. 5). With more of the lime molecule, anorthite formed in larger amount and typical troctolite was produced, with corrosion mantles[37] everywhere separating the two chief constituents. Where the segregated lime molecule preponderated over the magnesia, anorthite was produced in great abundance, exposing large areas to the corrosion of the still molten magnesia magma. In this case the magnesia molecule has been more or less completely consumed in the formation of corrosion products. The excess of alumina from the corroded anorthite has crystallized as microscopic grains of corundum in the midst of the magnesia-lime-alumina silicates produced by the corrosion. This is true of the anorthosites and the more feldspathic amphibolites.

The hypothesis here advanced does not preclude the possibility that alumina may have existed in excess of the demands of the anorthite molecule in the original magma, or may have been taken up by solution from aluminous rocks with which it came in contact. In either case the excess would crystallize as corundum of the first generation along with the anorthite, or possibly before it. It is quite probable that such a condition existed in many parts of the magma that were differentiated into the various facies of peridotite, amphibolite, and anorthosite. Such is doubtless the origin of the relatively large masses of pink to ruby-red corundum in the amphibolites of Buck Creek and Shooting Creek and in the anorthosites on the western slopes of Chunky Gal Mountain, as well as of the more extensive and valuable deposits of corundum in the peridotites themselves. This subject is more fully discussed in Chapter X.

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[37] The origin of these corrosion mantles is more fully discussed on p. 146.

We have, then, two generations of corundum. By far the greater part, including all deposits of commercial value, belongs to the first generation, and was formed by crystallization of the excess of alumina in the original peridotite magma. A very small quantity, however, occurring in microscopic grains, has been produced by an excess of alumina arising from the corrosion of anorthite by the still molten magnesian magma. In the latter case, it is presumable that the anorthite had crystallized, and was afterward, under other conditions, more or less corroded by the remaining magma, thus giving rise to the sheaths of intermediate minerals (corrosion mantles), or to the entire replacement of one of the constituents by aggregates of such minerals.

If in any case the lime-alumina molecule in the original magma had not been differentiated into anorthite at the time of crystallization, silicates of all the bases would be formed. This is the case in the amphibolites, which correspond very closely in composition to a magma consisting of anorthite and olivine molecules in the ratio of 2 to 1. Such a combination is represented in column I of the accompanying table, the iron of olivine being represented, for the sake of simplicity, by its equivalent of magnesia. By the removal of 8 per cent of the alumina and 1 per cent of magnesia to form corundum and spinel, and recalculation to 100 per cent, the values of column II are obtained. For comparison, the composition of the hornblende from amphibolite is given in column III, using the average of the two analyses given on page 84, the alkalies being recalculated as lime, the iron as magnesia.

Composition of theoretical olivine-anorthite magma (I and II) compared with amphibolite (III).

	I.	II.	III.
SiO_2	43.1	47.4	47.3
Al_2O_3	24.5	18.1	18.7
MgO	19.0	19.8	19.4
CaO	13.4	14.7	14.6
	100.0	100.0	100.0

I. Mixture of anorthite and olivine in ratio 2 to 1.

II. Same after removal of 8 per cent alumina and 1 per cent magnesia and recalculation to 100 per cent.

III. Composition of the hornblende that forms the essential constituent of the amphibolites, alkalies being reduced to equivalent of lime and iron to magnesia.

Thus we may consider the whole series of rocks associated with the peridotites of Buck Creek as derived from a highly magnesian silicate magma, containing small amounts of lime and alumina. The lime and alumina have combined with the magnesia, under certain conditions, to form the amphibole of the amphibolites and amphibole-peridotites. In other portions of the magma, the lime and alumina molecules have differentiated into anorthite, forming feldspathic peridotites, troctolites, and anorthosites. After the disposal of the lime and alumina, however, much the greater part of the magma remains to form the magnesian silicate, olivine, of dunite and the other peridotites. Thus the recognizable types produced in the Buck Creek area, arranged in the order of increasing lime and alumina and decreasing magnesia, are as follows:

1. Dunite, the granular aggregate of olivine; by far the most abundant.

2. Amphibole-peridotite, the amphibole-olivine rock; forming important areas, though much subordinate to the dunite.

3. Troctolite, the feldspar-olivine rock; occurring in still smaller masses, and by the introduction of augite passing occasionally into—

4. Olivine-gabbro, which occurs only as a minor facies of troctolite.

5. Amphibolite, the bright green aluminous amphibole-rock, frequently bearing pink and ruby corundum; occurring chiefly in numerous narrow dikes. With the introduction of anorthite, it often passes into—

6. Diorite, which occurs only in small amount, as a local facies of amphibolite, and sometimes forming a transition into—

7. Anorthosite, the nearly pure anorthite rock, which occurs only in small amounts. The occurrence of olivine in this rock occasionally gives rise to an olivine-anorthosite facies, which forms a transition into troctolite.

ORIGIN OF THE CORROSION MANTLES IN THE OLIVINE-FELDSPAR ROCKS.

The sheaths of intermediate silicates that everywhere separate the olivine from the feldspar in the troctolites and olivine-gabbros have been described on pages 79 to 81. As there stated, all constituents are well developed in places, permitting a comparatively easy determination of their character. They are usually two- or three-ply (Pl. XXXVIII, figs.

2, 3), and are sometimes more than a millimeter in thickness. In the typical three-ply development, the layers, beginning next the olivine, are as follows: (a) *enstatite,* in stout, colorless, parallel or radial columns; (b) *diopside,* short columns, often apparently continuous with the enstatite; (c) *actinolite,* in pale greenish fibers, parallel, radial, or gathered into sheaf-like bundles. Everywhere, except in a thin layer next the anorthite, the actinolite is intricately intergrown with irregular masses and tangled vermiculate stringers of *pleonaste.* The enstatite is the least variable, and is never absent; the diopside is the least constant, and is often wanting in portions of the sections; the actinolite has a much greater development than the other portions, and is somewhat variable, but never lacking altogether except for very short distances.

Dr. Adams regards the similar "reaction-rims" of the Canadian anorthosites as due to mutual reaction between the olivine and the plagioclase, probably between the olivine and the still molten plagioclase magma. The suggestion of magmatic corrosion in the latter clause seems to be the more plausible explanation. It is, of course, conceivable that intermediate products might be formed between minerals without the aid of fusion; but that the extensive development of anhydrous silicates composing the mantles under consideration were formed in this manner seems highly improbable. On the other hand, there seems to be no objection to the hypothesis that these aggregates represent the results of corrosion of one mineral by the still liquid magma of the other, when it had cooled almost to the point of consolidation, and it is entirely in accord with the conclusions set forth in this chapter as to the origin and nature of these rocks. As described on page 353, both laboratory experiments and observations in the field show that in a basic magnesian magma the aluminous minerals crystallize first. It is highly probable, therefore, that the feldspar in this rock represents the earlier crystallization. The relatively large size of the feldspars, while the olivine forms a much finer grained groundmass, would also sustain this view. The results of Dr. G. H. Williams'[38] investigations of the feldspathic peridotites of eastern Maryland are in perfect accord with this conclusion. He says:

> The olivine (the most characteristic constituent of this class of rocks) exhibits no very striking peculiarities. It is present in small rounded grains, forming the dark, compact groundmass in which crystals of the other minerals are porphyritically imbedded. The structure of these rocks is therefore quite an exceptional one for the family of peridotites: first, on account of the porphyritic[39] character, which is rare in members of this class, and,

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[38] Bull. U. S. Geol. Survey No. 28, 1886, p. 53.

[39] As the context shows, the term "porphyritic" here refers to large irregular masses, or anhedrons, and not to idiomorphic crystals.

second, because of the unusual position of the olivine in the groundmass, indicating that it is here the youngest, instead of the oldest constituent, as is generally the case.

Assuming that these rocks are intrusive masses and that the anorthite represents a deep-seated crystallization, sufficient change in condition might readily have been produced by intrusion into their present position to have caused the beginning of corrosion before cooling. This reaction would be quickly stopped, however, by the solidification of the rock. The products resulting from the combination of the aluminum, magnesium, and calcium silicates would, therefore, be limited to comparatively short distances from the original anorthite surface, and would appear in the solidified rock as mantles or sheets between the olivine grains and the anorthite.

This view is confirmed by the chemical constitution of the intervening minerals and their relations to the olivine on the one hand and to the anorthite on the other. In the typical three-ply mantles the minerals and their theoretical composition, in the order of occurrence from anorthite to olivine, are as follows:

Minerals of the corrosion mantles and their chemical formulas.

Anorthite	$CaAl_2Si_2O_8$
Pleonaste	$(Mg, Fe)Al_2O_4$
Actinolite	$Ca(Mg, Fe)_3(SiO_3)_4$
Diopside	$CaMg(SiO_3)_2$
Enstatite	$(Mg, Fe)SiO_3$
Olivine	$(Mg, Fe)_2SiO_4$

Neglecting for present purposes the isomorphous replacement of magnesium by iron, these formulas give the following percentage compositions:

Theoretical composition of minerals in three-ply corrosion mantles.

	SiO_2	Al_2O_3	CaO	MgO
Anorthite	43.2	36.7	20.1	...
Pleonaste	...	71.8	...	28.2
Actinolite	57.7	...	13.4	28.9
Diopside	55.6	...	25.9	18.5
Enstatite	60.0	...	...	40.0
Olivine	42.9	...	...	57.1

It will be noted that the intervening minerals are all compounds of the elements found in anorthite and olivine, and of these alone. The proportions of these minerals in the mantles cannot be estimated with any high degree of accuracy, on account of their variability. The enstatite is always present, and the actinolite, thickly intergrown with pleonaste except in its inner portion, is almost as constant. With all the variations in thickness of the mantle, the proportions of these three minerals do not fluctuate much. The diopside, however, is exceedingly inconstant and is often scarcely to be found at all. The following percentages represent approximately the constitution of the mantles as well as could be estimated in the several sections examined:

Mineral constitution of three-ply corrosion mantles.

Actinolite	35 per cent.
Pleonaste	25 " "
Diopside	15 " "
Enstatite	25 " "

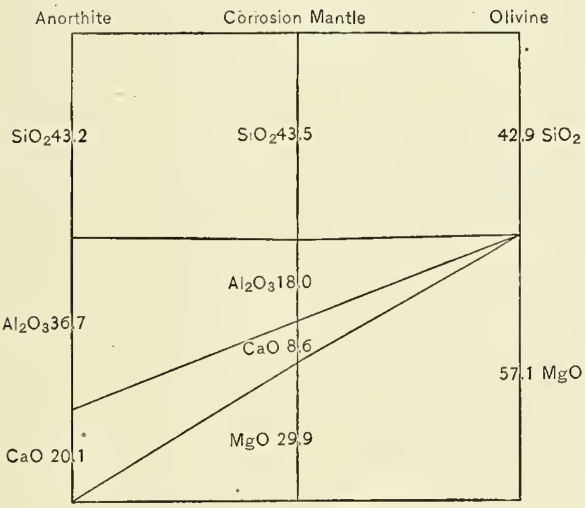


FIG. 6.—Diagram showing the chemical relations of the corrosion mantles to the adjacent minerals.

Using these proportions and the percentage composition of the various constituents as given above, we obtain the following values:

Chemical constitution of corrosion mantles and adjacent minerals.

	SiO_2	Al_2O_3	CaO	MgO
Anorthite	43.2	36.7	20.1	...
Corrosion mantles	43.5	18.0	8.6	29.9
Olivine	42.9	...	...	57.1

In the above table the silica is practically constant, alumina and lime decrease and magnesia increases in passing from the anorthite to the olivine, as illustrated diagrammatically in fig. 6.

Changing the proportions of the minerals constituting the mantles to any values within the limits of a reasonable approximation would produce but slight variations in the bulk composition. For instance, the proportions,

Actinolite 50, pleonaste 20, diopside 10, enstatite 20,

would yield the following bulk composition for the mantle:

SiO_2 46.4; Al_2O_3 14.4; CaO 9.3; MgO 29.9 = 100.0.

It will be observed that these values differ but little from those obtained above.

The individual constituents of the mantles are represented in their relative positions in fig. 7, with the adjoining anorthite on one side and

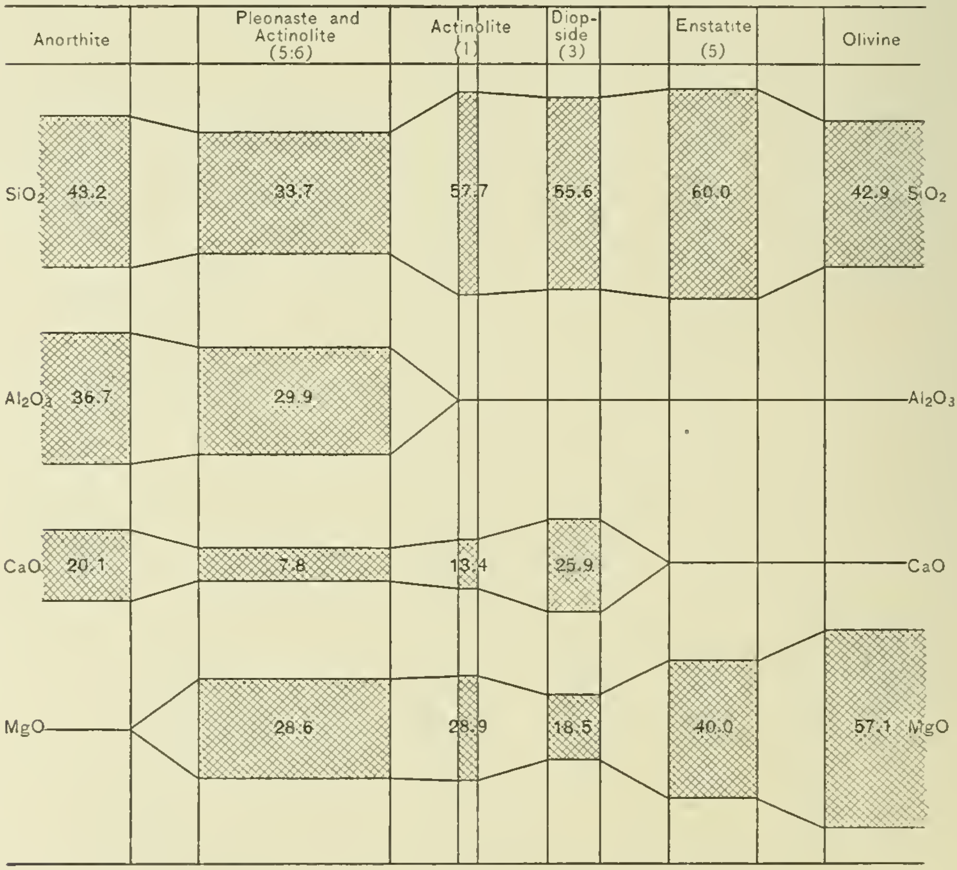


FIG. 7.—Diagram showing the chemical relations of the minerals constituting the corrosion mantles.

the olivine on the other. The proportions of the various minerals, as estimated above, are represented by the widths of the columns. Actinolite alone makes up but a very thin inner portion of the layer next the anorthite, hence most of this layer is represented by a mixture of actinolite and pleonaste in the proportions given.

It is noteworthy that while the magnesia supplied by the olivine magma decreases somewhat irregularly toward the anorthite, it is found throughout the entire thickness of the mantle. On the other hand, the lime from the anorthite is found only in the actinolite and diopside layers, while the alumina is confined to the pleonaste intergrown with the actinolite, which is in accord with the principles given on page 150 regarding the separation of alumina from a magnesian silicate magma. As described there, alumina does not have a tendency to unite with magnesia to form double silicates, but combines with any excess of magnesia that may be present to form the double oxides of the spinel group. The silica percentage of anorthite is almost exactly the same as that of the olivine; but the spinel, being confined to the actinolite layer, causes a relative decrease of silica there and a corresponding increase in the other portions of the mantle.

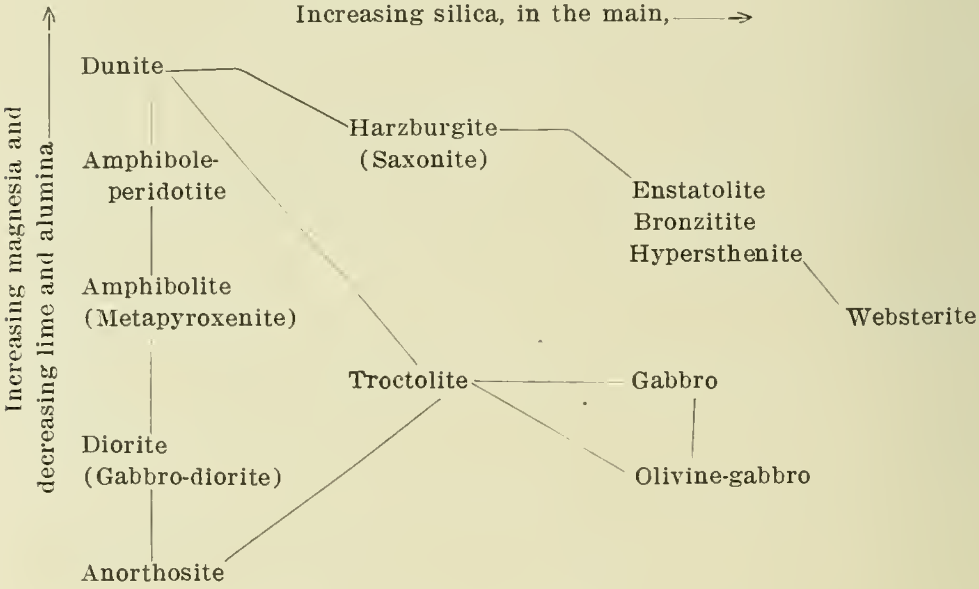
GENERAL PETROLOGY OF THE PERIDOTITE BELT.

As stated above, it is believed that the principles deduced from a detailed study of the Buck Creek area are applicable to the peridotites and their associates and derivatives, not only in the peridotite belt of western North Carolina, but also in its northward and southward extensions throughout the crystalline areas of eastern United States and Canada. The limited observations that have been made in other portions of the field, north and south, in connection with the work in North Carolina, are in full accord with the conception of genetic unity of the whole series of associated basic magnesian rocks. Further confirmation is also found in the results of petrographic studies in various limited areas of this region that have been published at intervals during the past two decades.

The series of rocks involved in the Buck Creek area, enumerated above, does not include quite all of the types represented within the State; but it is sufficiently inclusive and the relations are such as to clearly establish the essential unity of the whole series. With the addition of pyroxenites and pyroxenic peridotites, the list is practically complete for the whole region, only a few minor facies being omitted. It is also a noteworthy fact that several of these rock types are closely associated in almost every occurrence throughout the belt; and whether one or another preponderates in any particular region, the relations in all cases are essentially the same. Thus the peridotites, particularly dunite, prevail in North Carolina and Quebec, the pyroxenites and their derivatives seem to be most important in Pennsylvania, and the gabbros are very abundant in Delaware and Maryland; and yet complete lists of the types represented in these various regions are almost identical, and their petrology is found closely similar, except in relative abundance of the various types and in degree of alteration.

In a general way, the most prominent relationships of the primary rocks of this series in western North Carolina are represented in the accompanying table. The lines show the usual associations and transitions.

Relations of the principal types of primary basic magnesian rocks in western North Carolina.



Lines indicate usual associations and transitions.

The chemical relations of the most important of these rocks are more clearly brought out by the Hobbs-Brögger diagrams of Pl. XLV, in which molecular ratios are used.

AGE OF THE PERIDOTITES.

Until recent years it has been the custom of geologists to refer the whole of the Appalachian crystalline belt, largely on lithologic grounds, to Archean, or at least to pre-Cambrian age. The included peridotites, serpentines, etc., being found only in the crystallines, were consequently regarded as very ancient. This attitude is illustrated by the following extract from Dr. A. R. C. Selwyn's[40] outline of the geology of Canada which might be readily paralleled from the writings of many geologists little more than a decade ago:

> The soapstone, potstone or micarock, serpentine, and asbestos . . . . belong to the pre-Cambrian belts. . . . No fossils of any kind have yet been found in the rocks of these belts, and they are presumed to belong to the Huronian System, not only because of the geological position which they apparently occupy, but also on account of their close correspondence with it in physical aspect, and in mineral and lithological characters.

Since portions of these highly crystalline rocks are now regarded as extremely metamorphosed Paleozoic sediments, the old supposition of ancient origin is no longer to be accepted for any portion of the belt without other evidences than mere lithologic character. Hence in recent geologic work in several widely separated portions of this region, the effort has been made to determine, as nearly as possible, the age and succession of the various crystalline gneisses and schists, and the igneous masses by which they are intruded. Unfortunately but small areas, comparatively, of this great crystalline belt which extends from Alabama to Quebec and Newfoundland, have yet been studied and mapped in detail; and but little satisfactory correlation between these is possible. The accompanying table is an attempt by Dr. E. B. Mathews[41] to correlate the formations of the Maryland Piedmont with those of areas about New York, Philadelphia, and Washington, exclusive of igneous material. Dr. Mathews says:

> The determination of the age of these formations by fossils is impossible at the present time in Maryland, and the age assigned the various beds is therefore regarded as somewhat unproven, but the sequence here is comparable to that of the similarly situated areas farther north where they have been rorrelated with less metamorphosed beds bearing fossils. The lithological features and structural characteristics are the same in the different regions and it is probable that this correlation is the true one and that it must, perhaps forever, remain unproven for certain portions of the Maryland region where the beds are separated from other sedimentaries by igneous rocks.

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[40] Descriptive Sketch of the Physical Geography and Geology of the Dominion of Canada, Montreal, 1884, p. 13.

[41] Am. Jour. Sci., Vol. XVII, 1904, p. 143.

DR. E. B. MATHEWS' TABLE SHOWING CORRELATION OF CRYSTALLINES IN EASTERN PIEDMONT.

Red sandstones and shales of the Jura-Trias on the west and unconsolidated Coastal Plain deposits of Jurassic-Recent age on the east, separated from the underlying rocks by a marked unconformity.

	New York area.	Philadelphia area.	Maryland area.		Washington area.
	Merrill.	Bascom.	Williams.	Mathews.	Keith.
			Peach bottom slates.	Peach bottom slates.	
Silurian.	Hudson schist; mica schist with garnet, staurolite, fibrolite, cyanite.	Hudson mica schist and Wissahickon mica gneiss.	Phyllite, mica sch., muscovite gneiss (in part).	Cardiff quartz conglomerate. Wissahickon mica sch., including phyllite member at top.	
Cambro-Ordovician.	Stockbridge limestone.	Chester valley limestone.	Dolomite or marble.	Cockeyville marble.	
Cambrian.	Poughquag quartzite, thin-bedded white to brownish carrying tourmaline and muscovite.	Valley Forge and Edge Hill quartzite.	Setters quartzite.	Setters quartzite.	
Pre-Cambrian.	Fordham gneiss, gray, banded, potash-feldspar, quartz, mica, hornblende.	Arrowmink arkosic gneiss.	Biotite gneiss, muscovite gneiss (in part).	Baltimore gneiss.	Carolina gneiss (in part).

For comparison, the succession as worked out in the Green Mountains, central Massachusetts, and the Cranberry area (N. C.-Tenn.), is also given.

COMPARISON OF GEOLOGIC SUCCESSION IN GREEN MOUNTAINS, CENTRAL MASSACHUSETTS, AND WESTERN NORTH CAROLINA.

GREEN MOUNTAINS.	CENTRAL MASSACHUSETTS.	CRANBERRY AREA (N. C.—TENN.)
Pumpelly, Wolff, Dale.[42]	Emerson.[43]	Keith.[44]
Silurian.	*Silurian.*	
Rowe schist, silvery green. Greylock schist, muscovite, chlorite, and quartz schist. Bellowspipe limestone, more or less crystalline, generally micaceous and pyritiferous. Berkshire schist, muscovite, chlorite, and quartz schist. Stockbridge limestone (in part), coarse crystalline limestone and dolomite. (Hoosac schist, Silurian, equiv. Stockbridge to Greylock).	Leyden argillite, a dark slate or fine grained mica schist. Conway schist, coaly mica schist with limestone and quartzite. Goshem schist, flaggy mica schist. Hawley schist, sericite and chlorite schist. Savoy schist, sericite schist. Chester amphibolite, with serpentine, limestone, etc. (Equiv. to Bellowspipe?) Rowe schist, coarse sericite schist. Hoosac schist, albitic sericite schist.	
Cambrian.	*Cambrian.*	*Cambrian.*
Stockbridge limestone (in part). Vermont formation, gneisses, quartzite, and conglomerate.	Pelham quartzite, arenaceous, actinolitic. Becket gneiss, light gray biotite gn., sometimes conglomerate.	Watauga shale, purple, reddish, yellow, with sandstones and limestones. Shady limestone, grayish limestone with chert. Erwin quartzite, white sandstone and quartzite. Hampton shale, bluish and gray with thin sandstones. Unicoi formation, white sandstones and quartzite with shale and conglomerate.
Pre-Cambrian.	*Pre-Cambrian.*	*Archean.*
Stamford gneiss, coarse, banded, granitoid gneiss.	Washington gneiss, dark, compact, slightly fibrolitic.	Carolina gneiss, mica gneiss and mica schist.

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[42] U. S. Geol. Survey Monographs, Vol. XXXIII, 1894.
[43] Ibid., Vol. XXIX, 1898.
[44] U. S. Geol. Survey Folio No. 90, 1903.

While it may be possible to build up a fairly plausible correlation table including all these areas, using both lithologic characters and geologic succession, it must be conceded that such a table would possess but little real value, in the present state of our knowledge. In such highly metamorphosed rocks, and at such great distances lithologic characters have little weight in correlation, and geologic succession can be determined only with great difficulty. Often it cannot be satisfactorily made out at all. It is not surprising, therefore, that the investigators who have worked in the various regions referred to have arrived at some very diverse conclusions. This is particularly true in regard to the age of the peridotites, pyroxenites, etc.

Messrs. Pumpelly, Wolff, and Dale found amphibolite derived from basic intrusives in the gneisses of the "Vermont formation" of the Green Mountains which they correlate with Cambrian. Mr. G. C. Martin[45] later described an intrusion of dunite in the same rocks, on the west slope of Hoosac Mountain, near Cheshire.

Professor Emerson considers the Chester amphibolite-serpentine series as an altered limestone and groups it with Silurian formations, possibly the equivalent of the Bellowspipe limestone of Hoosac Valley. The peridotites that cut the gneisses of Pelham, Shutesbury, and New Salem, however, are regarded as igneous intrusions of Carboniferous age.

Dr. Merrill considers the amphibolites, pyroxenites, serpentine, etc., of the New York area as belonging to the same general period of igneous activity as the granite-gneiss, pegmatite and diorite of the same region; that is, "posterior to the deposition of the Hudson schists and therefore probably post-Silurian and prior to a part of the dynamic disturbances and crumpling of these rocks through which the intrusions have become schistose and even crumpled."

Dr. Julien,[46] in a recent exhaustive discussion of the "Genesis of the Amphibole Schists and Serpentines of Manhattan Island, New York," says of the serpentine: "Its genesis is interwoven with that of the amphibolite schists." In regard to the age of the latter, without assigning them to any definite period, he concludes as follows:

> These hornblendic schists then represent the most ancient group of intrusions into the Manhattan series, probably both as dikes and sills and mainly along one or two horizons, about 500 feet apart. In the larger sheets the trap was apparently porphyritic, with holocrystalline groundmass, of extreme basic composition and probably rich in pyroxene. While no definite evidence appears of the survival of that mineral in any rocks of the island, the

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[45] Am. Jour. Sci., Vol. VI, 1898, pp. 244-248.

[46] Bull. Geol. Soc. of America, Vol. 14, 1903, pp. 421-494.

> remnants of phenocrysts point to the gabbro-like character of these ancient dikes, and perhaps to their issue as a fringe to the now well-known center of eruption, 30 miles north, near Croton point, or more likely, I think, at an independent center of still greater antiquity in the Manhattan region. . . . Similar series of ancient intrusions occur in the tracts of crystalline rocks along the entire Atlantic belt, in whose metamorphism the earlier phase is well illustrated in the pyroxenic gabro-diorite series of Maryland, and one of the latest in the hornblende schists of Manhattan.

Dr. F. Bascom[47] considers the mica gneiss (Wissahickon) through which the basic eruptives cut in Pennsylvania and Maryland as probably of Silurian age, but adds:

> Positive proof for or against the Paleozoic age of the Wissahickon mica-gneiss is lacking. Until evidence for or against a faulted structure has been procured, or fossils are found in the interstratified limestone, the age of the Wissahickon gneiss and hence of the Cecil County mica gneiss must be considered as undetermined. It is either pre-Cambrian or lower Silurian. . . .
>
> If the igneous formations are intrusive in the mica gneiss they are of a later age and are either pre-Cambrian or Paleozoic. That they cannot be ascribed to a later era than the Paleozoic is rendered plain by the fact that they nowhere intrude into the Mesozoic formations which cover them in the north.
>
> They are for the present involved in the obscurity which surrounds the age of the mica gneiss.

Similarly Dr. Mathews[48] concludes in regard to the same region:

> From the fact that parts of this igneous complex are intruded into the rocks regarded as Silurian in age, this activity could not have ceased prior to the later portion of the Silurian and may have been much later. That the intrusions are not younger than Paleozoic time seems to be an inference well supported by the fact that they along with the sediments partake of the broad folding characteristic of the Appalachian region to the westward, which was probably developed contemporaneously in the rocks of the eastern and western portions of the State. Moreover, the sedimentaries of Jura-trias time show little folding of this type, their deformation being due almost entirely to very gentle folds and small faults of slight throw.

Mr. Keith,[49] on the other hand, considers the corresponding intrusions of the Washington (D. C.-Md.-Va.) and Cranberry (N. C.-Tenn.) quadrangles as of Archean age. The reason for this conclusion in the latter area is thus stated:

> Many small bodies of this formation are found within the areas of the Roan gneiss, few of them exceeding a quarter of a mile in width and 2 miles in length. Although these rocks break through and across the beds of Roan gneiss, and are thus seen to be distinct from and later than the gneiss, their

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[47] Md. Geol. Survey, Cecil County, 1902, pp. 103-113.
[48] Am. Jour. Sci., Vol. XVII, 1904, p. 156.
[49] U. S. Geol. Survey Folios Nos. 70 and 90.

association with the latter is close and marked and they are probably of about the same age. In this quadrangle the soapstone is not found in any other formation. In areas farther southwest it occurs sparingly in the Carolina gneiss as well as in the Roan gneiss. Rarely it is seen also in the shape of included masses in the eruptive Cranberry granite. It thus antedates the latter formation. Its alteration is as great as or greater than that of the Roan gneiss and exceeds that of the Cranberry granite, so that it appears to have shared in the earlier period of metamorphism which involved the Roan and Carolina gneisses. It thus is classed with the earliest part of the Archean.

It is obviously unnecessary to suppose that all facies of the magma were intruded into the gneisses and crystalline schists at the same time. In fact, it is evident in many localities that they are not exactly contemporaneous. In the Buck Creek area, for instance, the amphibolite occurs in the form of numerous dikes which intersect the peridotites (Pl. V); and this is a common relation in other localities also. And even the peridotites are not all of one generation, as shown by the dike of dunite that intersects the harzburgite near Balsam Gap, in Jackson County (Pl. X, A). Suggestions of similar time-relations may also be found in the occurrence of masses of dunite side by side and under exactly the same conditions, so far as could be determined, the one perfectly fresh and granular, the other completely serpentinized, as found 2½ miles east of Leicester, in Buncombe County (see p. 49). The websterite at Webster cuts the dunite, and is much less altered and less laminated. In Maryland both the peridotites and pyroxenites cut the gabbros with which they are associated.

Nevertheless the whole series is unquestionably to be regarded as a unit, whether intrusions are conceived to have taken place more or less continuously, through a single prolonged period of activity, or whether, as seems more probable, there were two or more such periods of intrusion. It is evident that most of the intrusions, if not all, occurred before the last orogenic movements in which the region has been involved, as shown by frequent development of lamination and other evidences of shearing in these rocks. They are quite certainly, therefore, of pre-Mesozoic age. This conclusion is further substantiated by the fact that the peridotites nowhere cut the Triassic formations with which they are closely associated in some localities. Further, they nowhere intersect the sedimentary series that has been called the "Ocoee" group in the southern Appalachians, although they appear in many places in North Carolina very near the borders of these rocks. Mr. Keith, of the U. S. Geological Survey, regards the Ocoee of North Carolina as of Cambrian age; while Dr. E. A. Smith, State Geologist of Alabama, reports Carboniferous fossils from rocks that have been called Ocoee in that State.

It is evident that sufficient data are not yet available for a satisfactory determination of the age of the peridotites. The close similarity of the petrographic conditions, however, throughout the peridotite belt, from Alabama to Newfoundland, makes it highly probable that the periods of intrusion of these rocks, whether one or many, were practically contemporaneous for the whole province. Hence the great bulk of these rocks throughout the belt belongs to the first period, or the early part of a prolonged period of activity, as the case may be; and these were afterward augmented by only small masses and dikes, some of which intersect the earlier bodies.

It will be observed from the general map (Pl. IV) that the peridotite belt lies in a region of great disturbance and intense metamorphism. This fact, together with its geologic relations to the northward, suggests the hypothesis that the principal period of intrusion was closely associated with the great orogenic movements of the Taconic revolution, at the close of the Lower Silurian (Ordovician) period. Prior to the epoch of Appalachian folding, this is the only period of widespread orogenic movement that has thus far been recognized in the eastern border region of the continent. The distribution of these intrusives through the belt of most highly metamorphic rocks from Alabama to Newfoundland, may well mark to a great extent the axis, or axes, of most intense folding and faulting. Many lenticular masses occupied spaces in the buckled and contorted strata, while here and there more extended and continuous bodies were formed in fissures. The later Appalachian disturbances, at the close of Carboniferous, would account for the widespread lamination developed in the peridotites, and would give occasion for the minor later intrusions.

The foregoing hypothesis is not offered as a final answer to the question of age of the peridotites. In view of the conflicting conclusions arrived at by geologists who have studied different parts of the belt, including a range from earliest Archean to Carboniferous, it is evident that much more painstaking work remains to be done before a satisfactory solution of the problem can be expected. Nevertheless it is hoped that this discussion may serve somewhat to emphasize the necessity for studying the various portions of the belt, not as isolated areas, but as parts of a connected and widely extended whole.

RELATIONS OF THE SECONDARY ROCKS.

Both mechanical and chemical forces have operated extensively to produce secondary rocks from all the types enumerated, and the origin of the resultant products cannot always be satisfactorily determined. One or the other set of forces usually greatly predominates and gives character to the rock, producing, typically, laminated rocks and schists on the one hand, and massive hydrous rocks on the other. In many cases, however, both classes of forces have operated upon the same rock, either simultaneously or successively, to such an extent as to fully impress upon it their distinguishing characteristics; and hence it would be impossible to satisfactorily classify the secondary rocks upon this basis. Talc-schist and chlorite-schist, for instance, might, with equal reason, be placed in either category. They are more readily classed in two groups, however, on the basis of their derivation from the original rocks by paramorphism or by hydration accompanied by more or less complete chemical alteration.

That the peridotites have been subjected to more or less dynamic action over a large part of the area is shown by the frequent and sometimes very pronounced development of lamination. In a few cases, as in a part of the Webster area, this structure is so highly developed that the rock might very properly be called a peridotite-schist. This condition is not usually accompanied by any unusual amount of alteration in the chemical character of the rock; on the other hand, the hydration products of similar rocks frequently occur as massive serpentine, talc, or chlorite rocks, with little or no structure of dynamic origin (see Chapter IV).

Much of the serpentine in other portions of the Appalachian region has also been traced to pyroxenite origin, particularly in Pennsylvania. Of the North Carolina serpentines, however, none has yet been recognized of this character; so far as their origin has been determined, and in most cases it is very apparent, they are altered peridotites.

Of the other two classes of hydrous secondary rocks mentioned above, talc and chlorite rocks, both massive and schistose, many have undoubtedly been derived from pyroxenites and amphibolites; and owing to the incompleteness of the change, this can often be determined by observation in the field. In many other instances, particularly where no unaltered remnants of the original rock are to be found, the determination of origin is naturally difficult, if not impossible, even with the aid of the microscope. The same is true of the hornblende-schists, which grade into hornblende-gneiss, and which are associated with the peridotites in great abundance in some localities, although by no means in all, as was formerly believed and reported by some of the earlier workers in this region. Gabbros and diorites, which commonly occur with the peridotites in Maryland, Delaware, and parts of Pennsylvania, are almost entirely absent from this region in North Carolina; but it is scarcely to be doubted that many of the hornblende and chlorite schists are the sheared and altered representatives of such rocks, while still others are clearly derived from amphibolites. Most of the amphibolites, in fact, are more or less distinctly laminated, in part, and every gradation to hornblende-schist and chlorite-schist may often be observed in a short distance.

The question whether the amphibolites, diorites, hornblende-schists, and hornblende-gneisses may not themselves have been derived by paramorphism from corresponding pyroxenic rocks, as in the Maryland and Delaware gabbro areas, has been kept in mind during this investigation; and several sections (C12, B54, B70, B71) from the dioritic and gabbroic facies of the amphibolites on Buck Creek and Shooting Creek were found to contain colorless augite extensively altered into green amphibole. These transition types show unquestionably the existence of gabbro-diorites at these localities and render it highly probable that many, if not all of these rocks, as well as similar amphiboliferous rocks in other parts of the region, have had a like origin. Although in the majority of cases such an origin may be incapable of positive proof at the present time, the conditions observed in these localities, particularly when viewed in the light of the results obtained by Dr. Williams[50] and Dr. Chester,[51] in Maryland and Delaware, must be regarded as strong presumptive evidence. Some of these rocks should therefore be called gabbro-diorites, and extending the same system of nomenclature, others should be known as gabbro-diorite-gneisses and pyroxenite-amphibolites, or metapyroxenites.

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[50] Bull. U. S. Geol. Survey No. 28, 1886.

[51] Bull. U. S. Geol. Survey No. 59, 1890.

CHAPTER VI.

PHYSICAL AND CHEMICAL PROPERTIES, VARIETIES, AND USES OF CORUNDUM.

THE NOMENCLATURE OF CORUNDUM.

Various names for corundum derived from its hardness, color, parting, structure, etc., have been given to its different varieties. The number of these names may be accounted for in part by the fact that early in the history of the mineral its different varieties were described as different minerals and it was not until the early part of the last century that they were all brought under one head. The following names have been used to designate the different varieties of this mineral, the list being compiled from Dana's System of Mineralogy, sixth edition; Dictionary of the Names of Minerals, by Chester; Catalogue of Minerals and Synonyms by Egleston; and the names used by the lapidaries.

Names applied to the different varieties of Corundum.

Sapphire.

Amethiste orientale.
Anthrax, *Theophrastus*.
Apyrote.
Asteria, *Pliny*.
Asteriated sapphire.
Asterie.
Barklyite, *Stephen*.
Blue du roi.
Blue sapphire.
Bronze corundum (p. 189).
Carbunculus, *Pliny*.
Cat sapphire.
Chlor sapphire.
Corindon hyalin, *Haüy*.
Corindon perfect.
Corindon télésie, *Brongniart*.
Emerald.
Emeraude.
Emeraude orientale.
Green sapphire.
Hyacinth.
Hyacinthos, *Pliny*.
Hyaline.
Jacut (Arabian).
Lichnis, *Pliny*.
Luchs sapphir.
Luchs sapphire.
Lychnis, *Pliny*.
Lynx sapphire.
Occidental amethyst.
Opalescent sapphire.
Opaline.
Oriental aquamarine.
Oriental chrysolite.
Oriental emerald.
Oriental hyacinthe.
Oriental peridot.
Oriental ruby.
Oriental sapphire.
Oriental topaz.

Sapphire.—*Continued.*

Orientalisk rubin, *Wallerius*.
Pink sapphire.
Pearl corundum (p. 189).
Rubie étoile.
Rubin.
Rubis.
Rubis oriental, *Werner*.
Sagenite corundum (p. 190).
Salamstein, *Werner*.
Salamstone.
Saphir, *Werner*.
Saphir asteria.
Saphir blanc.
Saphir de chat.
Saphir étoile.
Sapphire.
Sapphirus, *Wallerius*.
Spath adamantine, *Delameth*.
Star sapphire.
Star stone.
Télésia, *Haüy*.
Télésie, *Haüy*.
White sapphire.
Yellow sapphire.

Corundum.

Adamant, *Kirwan*.
Adamantine spar, *Kirwan*.
Adamas siderites, *Pliny*.
Alumina.
Anthrax.
Armenian stone (*King*).
Corindon, *Haüy*.
Corindon adamantine, *Brongniart*.
Corindon harmophane, *Haüy*.
Corivendum.
Corivindum, *Woodward*.
Corundite.
Corundum, *Greville*.
Corundurnite.
Demantspath, *Klaproth*.
Diamond spar.
Gyrasola, *Kirwan*.
Hard spar.
Imperfect corundum, *Greville-Bournon*.
Karund, *Hind*.
Korund, *Werner*.
Kurund, *India*.
Rhombohedral corundum, *James*.
Rhombohedrischer corund, *Mohs*.
Soimonite.
Spath adamantine, *Delameth*.
Thoneride.

Emery.

Acone ex Armenias, *Theophrastus*.
Armenian stone.
Coridon granuleux, *Haüy*.
Emeri.
Emeril, *Haüy*.
Emerite, *Shepard*.
Emery.
Fer oxyde quartzifere, *Haüy*.
Granular corundum.
Grinding spar.
Naxium, *Pliny*.
Naxium ex Armenia, *Pliny*.
Pyrites vivus, *Pliny*.
Schmergel.
Schmirgel.
Smergel, *Wallerius*.
Smirgel.
Smiris, *Agricola*.
Smiris ferrea, *Wallerius*.
Smyris, *Agricola* and *Disscorides*.
Spinel emery (p. 193).

At the beginning of the last century, in 1805, Haüy first formally united these different varieties under the one head of corundum for the species. At the present time there are three names recognized in the arts for the three main varieties, depending on purity, state of crystallization, and structure. These subdivisions are (1) sapphire, (2) corundum, and (3) emery.

1. *Sapphire.*—Under this head are included all the highly colored varieties of corundum, which are transparent to translucent and are of value as gems (see p. 177).

2. *Corundum.*—This variety includes all those of dark and dull colors and also the massive, lighter colored varieties that are not transparent, as the blue to gray, brown, and white. All corundum, except emery, that is not valuable for gems is brought under this head. (For further description see p. 190).

3. *Emery.*—Included under this variety is the intimate mixture of very fine, granular corundum with magnetite and sometimes with hematite. The ore in appearance is very similar to a fine-grained iron ore, with which it was at first often confused. A full description of emery is given on page 192.

CRYSTALLINE STRUCTURE.

Corundum crystallizes in the rhombohedral group of the hexagonal system, in which the fundamental rhombohedron differs but very little in angle from that of the cube. There is considerable variation in the type of the crystals from the different localities, but in their common development they usually show the forms of the prism and pyramid of the second order, *a* $(11\bar{2}0)$ and *n* $(22\bar{4}3)$, in combination with the base, *d* (0001) and the rhombohedron, *r* $(10\bar{1}1)$.

There are two common types of crystals; one, prismatic, in which the prism, *a* $(11\bar{2}0)$, is the prominent form, which is sometimes terminated simply by the base, *c* (0001) (fig. 8), and again by the base and rhombohedron *r* $(10\bar{1}1)$ (Pl. XVI, fig. 3), or, by the base, rhombohedron and pyramid, *n* $(22\bar{4}3)$ (Pl. XVI, fig. 7); the others are flat-tabular crystals, in which the basal plane is the prominent form and which are often simply a combination of the base and the rhombohedron (Pl. XVI, fig. 2), or of the base and the prism (fig. 9), or a combination of the two (Pl. XVI, fig. 4).

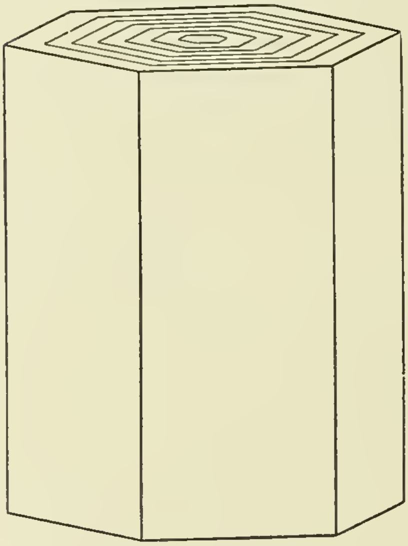
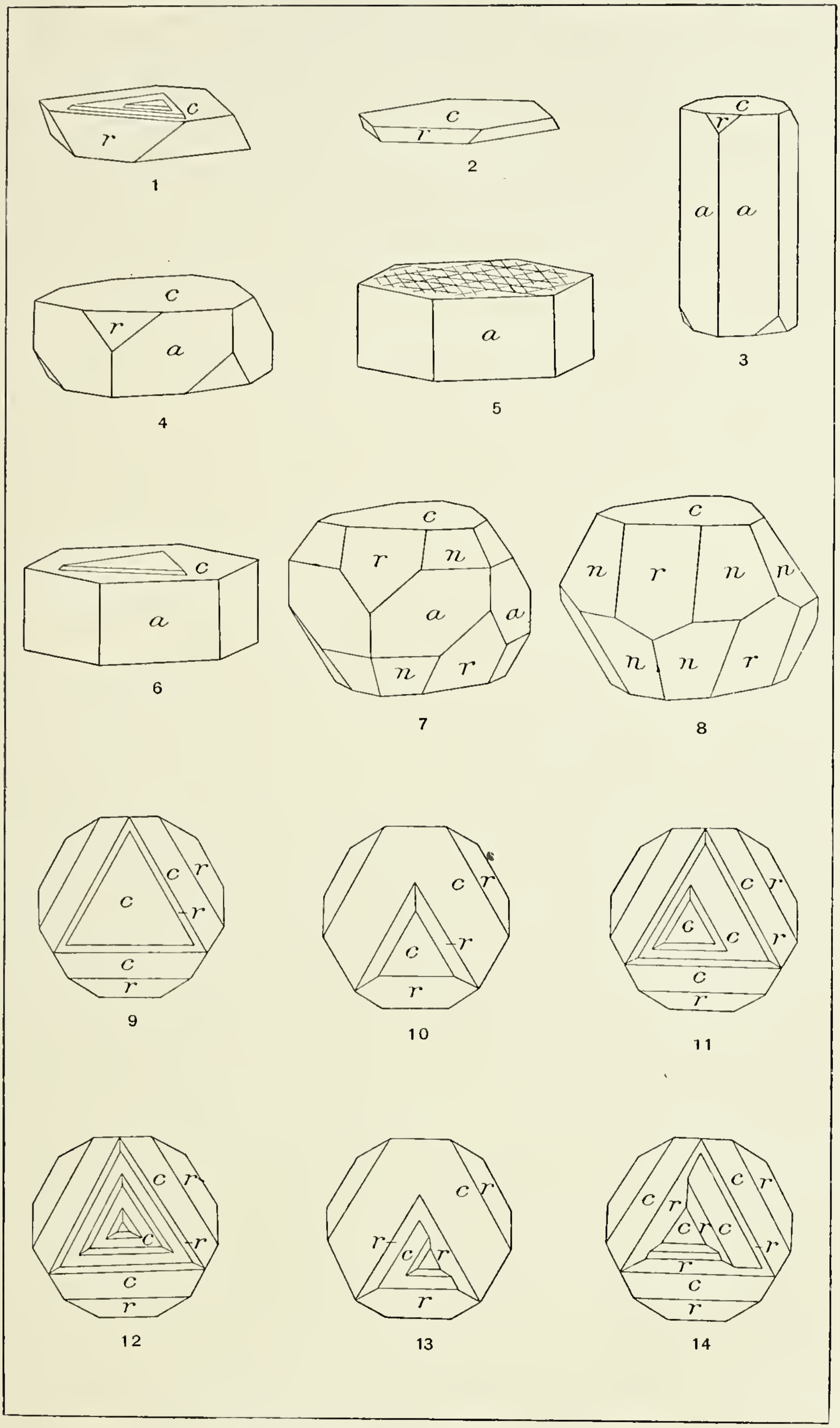


FIG. 8.—Prismatic corundum crystal terminated by base.



CORUNDUM CRYSTALS FROM NORTH CAROLINA.

Pyramidal crystals, in which the pyramid of the second order, n $(22\bar{4}3)$, is the most prominent form, are common in but few localities; these are represented by fig. 10 and Pl. XVI, fig. 8. The more complicated forms of crystals, fig. 11, are rarer and it is the simple crystals that are the most often observed.

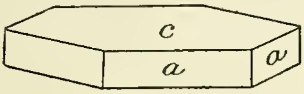
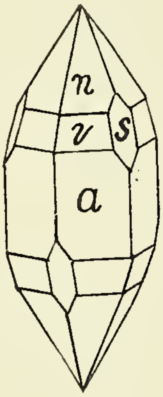


FIG. 9.—Tabular corundum crystal, showing base and prism.



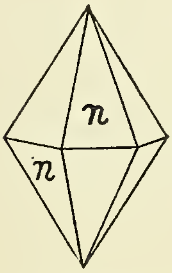


FIG. 10.—Pyramidal crystal of corundum from Ceylon.

FIG. 11.—Rarer form of corundum crystal.

The height of the vertical axis is $c = 1.363$.

The following forms have been observed in corundum:

c (0001), base.
m $(10\bar{1}0)$, prism, first order.
a $(11\bar{2}0)$, prism, second order.
f $(71\bar{8}0)$, di-hexagonal prism.
y $(10\bar{1}5)$, one-fifth rhombohedron.
δ $(10\bar{1}3)$, one-third rhombohedron.
d $(10\bar{1}2)$, one-half rhombohedron.
r $(10\bar{1}1)$, unit rhombohedron.
x $(30\bar{3}2)$, three-halves rhombohedron.
b $(70\bar{7}2)$, seven-halves rhombohedron.
q $(70\bar{7}1)$, seven rhombohedron.
n $(01\bar{1}1)$, minus-one rhombohedron.
s $(02\bar{2}1)$, minus-two rhombohedron.
β $(07\bar{7}2)$, minus-seven-halves rhombohedron.

o $(22\bar{4}5)$, pyramid, second order.
n $(22\bar{4}3)$, " " "
Σ $(7\ 7\ \overline{14}\ 9)$, " " "
w $(11\bar{2}1)$, " " "
k $(7\ 7\ \overline{14}\ 6)$, " " "
v $(44\bar{8}3)$, pyramid, second order.
u $(11\ 11\ 22\ 6)$, " " "
z $(22\bar{4}1)$, " " "
λ $(7\ 7\ \overline{14}\ 3)$, " " "
θ $(8\ 8\ 16\ 3)$, " " "
ν $(44\bar{8}1)$, " " "
ω $(14\ 14\ 28\ 3)$, " " "
i $(42\bar{6}5)$, di-hexagonal pyramid.
g $(32\bar{5}4)$, " "
ρ $(2\ 8\ 10\ 9)$, " "

In the following table a list of the more common angles of corundum are given, which have been calculated from the fundamentals of Miller.[1]

$c \wedge a = 90^\circ$.
$c \wedge m = 90^\circ$.
$c \wedge d = 38^\circ\ 12'$.
$c \wedge r = 57^\circ\ 34'\ 8''$.
$c \wedge x = 67^\circ\ 3'$.
$c \wedge s = 72^\circ\ 22'\ 30''$.
$c \wedge n = 61^\circ\ 11'$.
$c \wedge v = 74^\circ\ 37'$.
$c \wedge z = 79^\circ\ 36'$.
$m \wedge m = 60^\circ$.
$a \wedge a = 60^\circ$.
$a \wedge r = 43^\circ\ 2'$.
$a \wedge s = 34^\circ\ 22'\ 30''$.
$r \wedge r' = 93^\circ\ 56'$.
$s \wedge s' = 111^\circ\ 15'$.
$n \wedge n' = 51^\circ\ 58'$.
$v \wedge v' = 57^\circ\ 38'\ 30''$.
$z \wedge z' = 58^\circ\ 55'$.

Where the crystals are small they are usually well developed, with smooth faces and sharp edges, the larger crystals are rough, striated, often rounded, and taper slightly toward the end like a barrel, so that they are sometimes called "barrel corundum."

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[1] Min. 1852, p. 242; and Dana Mineralogy, 6th ed., 1892, p. 211.

The basal plane often shows characteristic striations which are parallel to three intersections of the base, *c*, and the rhombohedron, *r*, as shown in Pl. XVI, fig. 5. The lines are often very sharp and distinct, especially on the flat tabular crystals. Then again, the basal plane is marked by a series of concentric bands of inclusions forming regular hexagons whose sides are parallel to the edges of the base, *c*, on the prism of the second order, *a*, as represented in fig. 8. These hexagonal markings vary considerably in size, distinctness, and regularity, and have been observed on many varieties of corundum. Sometimes the base is divided into sections by lines radiating from a point at the center to the edges of base, *c*, on to the prism, *a*. Very rarely where this zonal structure has been observed but one hexagon is to be seen on any basal section cut from the crystal and the diameter of the hexagon grows less as the center of the crystal is approached, where they terminate in a point. From the center to the opposite end of the crystal the reverse is true. This peculiar arrangement of inclusions is well shown in some of the rubies from Cowee Creek, Macon County, and is represented in fig. 12. This arrangement of inclusions is similar to that of the carbonaceous material observed in the staurolite near Grafton, New Hampshire.[2]

Twin crystals.—The common twinning plane that has been identified is parallel to the rhombohedron, *r* $(10\bar{1}1)$. Penetration-twins have been observed, but they are not at all common (see fig. 24, p. 208). The twinning that is most prominent on corundum is polysynthetic, that is the twinning has been repeated forming a series of plates or lamellæ in twin position. This style of twinning often produces a laminated structure and sometimes it gives rise to a surface which is distinctly striated, which consists of minute reëntrant and salient angles. This twinning also produces the rhombohedral parting described below.

Recently[3] a new twinning plane has been identified in corundum which is parallel to the base *c* (0001). The crystals in which this twinning plane is developed were gray and ruby-red in color, and have been found sparingly in the Ruby mine at Caler Fork of Cowee Creek, Macon County, N. C. They were first observed by Mr. W. E. Hidden and, as stated by him, the two best crystals measured 6 mm. in diameter and length. They are characterized by reëntrant angles (*n*, $22\bar{4}3$) on the prismatic faces (*a*, 1120) and some slight natural corrosion. This type of twinning is represented in fig. 13.[4]

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[2] Am. Jour. Sci., 3d ser., Vol. XLVII, 1894, p. 83.

[3] William E. Hidden, Am. Jour. Sci., Vol. XIII, 1902, p. 474.

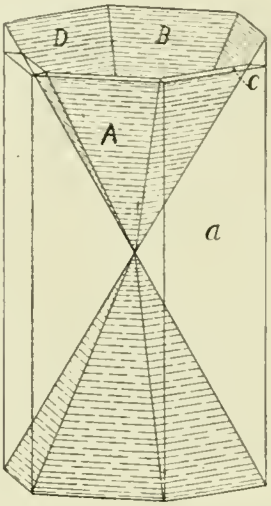

FIG. 12.—Corundum crystals, showing geometrical arrangement of inclusions.

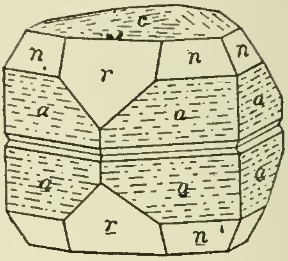

FIG. 13.—Twin crystal of corundum from Macon County, N. C.

PARTING.

What was considered by the earlier mineralogists to be a cleavage in corundum has been shown to be a parting produced by the action of mechanical or chemical forces or perhaps of both acting together. As early as 1802,[5] the Count de Bournon had pointed out that certain corundums, especially sapphires, did not show any cleavage, but broke with a conchoidal to splintery fracture. Prof. J. W. Judd[6] has shown that unaltered corundum does not exhibit any trace of cleavage.

There are three crystallographic planes along which parting has been observed:

I. Parting has been observed parallel to the base, *c* (0001). Professor Judd says:

> That this basal plane is a solution plane of corundum is shown by the fact that the crystals from Burmah and other localities which have undergone partial conversion into diaspore and hydrous silicates, exhibit a remarkable step-like structure (resembling that of the "Babel quartz" on a very minute scale), showing that the chemical disintegration of the crystal has been

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[4] Reproduced from figure by Mr. John C. Blake of the Yale Mineralogical Laboratory.

[5] Description of the Corundum Stone and its Varieties, Phil. Trans., Vol. XCII, 1802. pp. 233-326.

[6] Min. Mag., Vol. XI, 1895, p. 50.

> governed by the existence of these solution planes. This fact is beautifully illustrated in the fine ruby presented to the British Museum by Mr. Ruskin, which exhibits the shaly structure due to corrosion and the natural etched figures in a very striking manner. I have no doubt that this fine ruby came from Burmah, and many small specimens which I have examined from the same locality exhibit similar characters. As in the case of murchisonite and diallage, the multiplication of cavities along certain planes gives rise to a plane of weakness or a parting scale in the crystal along which it readily divides.

The basal parting plane often shows a pearly or sometimes submetallic luster, which is decidedly different from the vitreous to adamantine luster of the crystal faces.

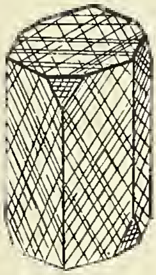

FIG. 14.—Corundum crystal, showing striations due to rhombohedral parting.

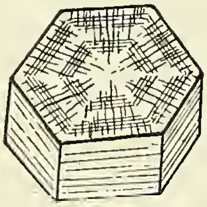

FIG. 14a.—Corundum crystal, showing striations due to basal parting.

This basal parting, although perfect for a portion of the crystal, may be interrupted and its continuation will be stepwise along a nearly parallel plane. In general, crystals cannot be broken into plates with parallel faces as would be the case if the mineral possessed cleavage.

II. The parting planes parallel to the unit rhombohedron *r* $(10\bar{1}1)$, are twinning planes of corundum, and there is reason to believe that this lamellar twinning of corundum has been caused by pressure. It has been observed that a crystal without this rhombohedral parting may be destitute of any lamellar structure; or, as Tschermak has pointed out, these may be developed on two of the rhombohedral planes and almost or entirely lacking on the third.

III. A third parting plane, which is parallel to the prism *a* $(11\bar{2}0)$, is seldom observed by the actual breaking of the corundum crystals; but can be seen in thin sections under the microscope. It is best seen in the corundum from the Chentilun Hills, in Siam.

Of these three partings, II, which is parallel to the rhombohedron, is the only one that follows a twinning plane of corundum. The striations observed on corundum crystals, which are due to parting, are shown in figs. 14 and 14a. The parting planes developed on the corundum interfere materially with the production of the commercial corundum. Many corundums which exhibit this parting in the larger fragments soon begin to break with irregular fracture, so that only the higher numbers of the commercial corundum (coarser grades) show any traces of this parting in them. In some the parting is so developed that even in the finer numbers particles of corundum still show parting, which diminishes greatly their cutting quality or efficiency. In crushing ore in which the parting is developed to this extent a great deal of fine powder called flour corundum is produced, causing a waste of considerable material.

If this parting is developed in corundum that has been made into a wheel, its cutting power is greatly reduced; for when the wheel is in use, the corundum grains, instead of breaking with an irregular fracture and producing a cutting edge, split along the planes of parting and the wheel crumbles away too rapidly.

FRACTURE.

As has been said, the unaltered corundum does not show the development of these parting planes, but breaks with an irregular to conchoidal fracture. It is this irregular fracture of corundum that is one of the factors in determining its value, and that is necessary to produce the best cutting and most durable edge on the grains of corundum. If, however, the parting planes are developed, the corundum will break along these, since they offer the least resistance.

HARDNESS.

Next to the diamond, corundum is the hardest mineral known; but the hardness varies, although but slightly, in the different varieties. The hardness usually ascribed to corundum is 9, which is that of the blue sapphire variety, but not all corundums reach this. The ruby is slightly less, ranging from 8.8 to about 9.

In emery it is, of course, the corundum that gives it its high degree of hardness, even though the grains of corundum themselves cannot be distinguished.

The hardness of corundum must not be confused with its abrasive efficiency, for while most corundums differ but slightly in hardness, there is often a great difference in the amount of abrasive work that they are able to do. The hardness represents the resistance offered by the corundum to abrasion or to scratching by other substances and also its ability to scratch. Any fragment of corundum that is entirely free from alteration or decomposition will, when tested as to its hardness, be found to be close to 9, and will scratch any of the minerals, except the various varieties of corundum and the diamond. This same material, however, may have a cutting efficiency that is very much below that of another corundum whose hardness is just the same.

ABRASIVE EFFICIENCY.

The abrasive efficiency of a corundum is dependent upon the degree to which its particles, when it is in use, break and wear away so that new cutting edges are kept exposed, instead of becoming rounded. This efficiency is measured by the amount of abrasion effected upon a given surface in a given time.

Many experiments of various kinds have been made to measure the abrasive efficiency of corundum, but it is becoming apparent that the only safe way to determine its cutting power is to have it made up into wheels and to test them as if they were in actual use.

A method that has been in vogue for many years, for measuring the abrasive efficiency of corundum is that described by Dr. J. Lawrence Smith.[7] A weighed amount of the mineral is ground to an impalpable powder on a weighed glass plate by means of an agate surface. The loss in weight of the glass plate is considered the measure of the abrasive efficiency of the corundum, which was designated by Dr. Smith as the "effective hardness."

In the following table are given the effective hardnesses as determined by him for many foreign corundums and emeries:

Smith's table of hardnesses of corundums and emeries.

Corundum.		*Emery.*	
Sapphire (blue) of India	100	Kulali	57
Ruby of India	90	Samos	56
Corundum, Asia Minor	77	Nicaria	56
Nicaria	65	Kulali	53
Asia	60	Naxos	46
India	58	Nicaria	46
Asia	57	Naxos	44
India	55	Ephesus	42

Prof. W. H. Emerson[8] has made a series of experiments upon the abrasive efficiency of corundum according to the method described by

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[7] Am. Jour. Sci., 2d ser., Vol. X, 1850, p. 362.

[8] Trans. Am. Inst. Min. Eng. Vol. XX, 1899, Feb. meeting.

Smith, in which the loss in weight of the glass plate divided by the weight of the corundum is taken as the abrasive efficiency. A series of experiments was also made by the following method:

> A shallow brass box was fitted to the top of the rotating spindle of a centrifugal machine so that the bottom should be horizontal. A steel plate ¼ inch thick and 5 inches in diameter was placed in this and wedged tight. The test-piece of corundum, a small cylinder ⅝ inch in diameter and about 0.8 inch long, made by cementing corundum powder, was pressed upon the surface of the plate with the weight of 3.25 pounds, and the plate was rotated with a speed of 300 revolutions per minute. The test-piece was moved at intervals so as to grind nearly the whole surface of the plate. At the expiration of a certain time the plate and test-piece were weighed, and the loss of weight of the plate, divided by the loss of weight of the test-piece was taken as the efficiency of the corundum.

In the table below, the results are given as determined by both methods:

Results of tests of abrasive efficiency of corundums.

Locality.	By Smith's Method.	By Emerson's Method.
1. Transylvania County, N. C.	.326	...
2. Acworth, Ga.	(4) .207	(1) 24.5
2a. “ “	...	22.8
3. Iredell County, N. C.	...	13.7
3a. “ “ “	...	15.8
4. Macon County, N. C.	(3) .309[9]	(4) 16.4
4a. “ “ “	...	18.1
5. Sapphire, N. C.	(2) .311	(2) 22.9
5a. “ “	...	16.3
6. Laurel Creek, Ga.	(1) .409	(3) 22.0
7. Track Rock, Ga.	.274	...
8. Towns County, Ga.	.255	...

Other experiments were made by Emerson, in which the method was slightly different, but there was always considerable variation in the results obtained. These results are not accurate, and it is not probable that they represent even approximately the relative abrasive efficiency of the materials tested. As was stated before, the only satisfactory way to determine the relative abrasive efficiency of different corundums is to make them into wheels of the same size and composition—whether vitrified, chemical, or cement—and to test each of these wheels by its abrasive action on a different part of a piece of steel of uniform hardness, the wheels to be mounted on the same machine and to make the

[9] This test was varied slightly from the regular Smith method.

same number of revolutions per minute; the bond of the wheel and the grain of corundum to be made as nearly uniform as possible.

It has been thought by many that the water contained in many of the corundums lowered their abrasive efficiency and that this efficiency could be calculated by making a determination for water; but while the water content of a corundum does undoubtedly affect its abrasive efficiency, the determination of this water would not permit of any accurate estimation of the abrasive efficiency.

In the following tables are given the percentage of water and the relative abrasive efficiency of certain corundums as determined by Emerson's and Smith's methods:

Emerson Method.

	No. 2.	No. 5.	No. 6.	No. 4.	No. 3.
Abrasive efficiency	24.5	22.9	22.0	18.1	15.8
Water, per cent	2.89	.53	.77	.78	.45

Smith Method.

	No. 6.	No. 1.	No. 5.	No. 7.	No. 8.	No. 2.
Abrasive efficiency	.409	.326	.311	.274	.255	.207
Water, per cent	.77	.40	.53	.72	1.17	2.89

It will be seen from these tables that the difference in abrasive power is not at all dependent upon the amount of water that enters into the composition of the corundum. Where, however, there has been an alteration of the corundum into hydrous oxides, as diaspore, the abrasive efficiency will be lowered according to the percentage of the alteration. The abrasive efficiency of a corundum, instead of depending upon its chemical composition, probably depends upon its physical structure or composition. As a result of a series of experiments made to test the abrasive efficiency of various corundums, emeries, and other abrasives, which were in the form of wheels constructed of these materials, Mr. Charles N. Jenks[10] gives the corundum from Sapphire, Jackson County, North Carolina, the highest abrasive efficiency, and that of Corundum Hill, Macon County, and of Laurel Creek, Rabun County, Georgia, next highest. Of the emeries (of which, as has been said before, it is the corundum that determines the cutting power) the Chester emery was shown to have a higher abrasive efficiency than the Turkish, which comes next, or the Naxos emery.

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[10] Sci. Am. Supplement, No. 988, Dec. 8, 1894.

When made up into wheels some varieties of corundum do not show as high cutting efficiency as some of the emeries; for while the corundum wheel at the start cuts much more rapidly than the emery wheel, the grains quickly become rounded and the wheel is soon unfit for further use, so that its total cutting efficiency is much below that of the emery wheel.

Experiments made according to the method described by Dr. J. Lawrence Smith show that the blue sapphire corundum has the highest cutting power, and this is often reckoned as the standard, with an abrasive efficiency of 100, the cutting power of the others being rated according to this. All of the transparent corundums, of whatever color, which show no parting planes, except to a very slight degree, are very close to 100 in abrasive efficiency; but the non-transparent varieties and those in which parting is considerably developed are very low in abrasive power.

A long series of experiments on the various corundums made up into wheels, and on steel and iron of different hardness will be necessary before even an approximately accurate table of their abrasive efficiency can be made. It must be borne in mind that the structure of the material to be abraded—that is, soft or hard, granular or stringy, etc.—is a factor in determining what abrasive is best suited for particular work. Thus, in some instances, garnet will do better work than the best corundum.

SPECIFIC GRAVITY.

The specific gravity of corundum is about 4, varying from 3.95 to 4.10. Its high specific gravity affords a means of recognizing it in the field, for few of the non-metallic or light-colored minerals are as heavy as this, and none of these is likely to be found in the corundum regions.

LUSTER AND COLOR.

The luster of corundum is adamantine to vitreous, while that of emery is metallic to submetallic. On the basal surface of corundum the luster is sometimes pearly.

Corundum occurs in a great variety of colors: ruby-red to rose and all intervening shades, pink, sapphire blue, dark blue to pale blue, emerald green and various other shades of green, violet to purplish, yellow of various shades, brown, gray, black, and some is colorless. Frequently there is a mottling and also an alternation of colors, the alternation appearing in bands parallel to the base or in concentric hexagonal layers. Occasionally one end of a crystal is of one color, the opposite end is of another, and the middle portion nearly colorless, this being especially true of the gem corundum found at Corundum Hill, Macon County, N. C.

OPTICAL PROPERTIES.

Pleochroism—that is, the property by which a crystal shows different colors when light passes through it in different directions—is very strongly marked in the deep colored varieties of corundum, especially sapphires and rubies. For instance, the ruby shows a deep-red color when viewed in the direction of the vertical axis and is much lighter in color when viewed at right angles to this. By means of this property corundum gems are readily distinguished from spinel, garnet, and other gem minerals.

The action of the Roentgen or X-rays upon corundum gems, as ruby and sapphire, is another means of distinguishing them from other minerals that resemble them, and from artificial stones. The corundum gems allow these rays to pass through them freely; the diamond allows ten times more to pass. Dr. Doelter[11] has arranged the minerals into the following groups, according to their resistance to the passage of the X-rays, the diamond allowing the rays to pass through it the most freely:

1. Diamond.
2. Corundum.
3. Talc.
4. Quartz.
5. Rock salt.
6. Calcite.
7. Cerussite.
8. Realgar.

Corundum is usually uniaxial, with negative double refraction; but some varieties have been found that are abnormally biaxial. The mean index of refraction is high, being about 1.765. The double refraction is only .008 to .009 or about the same as quartz. For the indices of refraction, see table on page 179.

CHEMICAL COMPOSITION OF CORUNDUM.

Theoretically pure corundum consists of alumina only (Al_2O_3), but with few exceptions all the specimens examined contain also other chemical compounds, the principal ones being silica (SiO_2), water (H_2O), and ferric oxide (Fe_2O_3). Nearly all corundums contain water, which varies in amount from a trace to 2 per cent or more. Where silica and ferric oxide occur their amounts also vary. Some specimens show none of these; others show as high as 5 per cent of one or the other. Of course these statements do not apply to emery, which is a mechanical mixture of corundum and magnetite; but they do apply to corundum separated from the mixture, and the impurity in this corundum is usually ferric oxide.

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[11] Mitth. des Naturwissenschaftlicher Vereins f. Steiermark, Jahr. 1895; Mar. 26, 1896; and Mineral Research, U. S., 1895-96, U. S. Geol. Survey, p. 922.

The purest known forms of corundum are the transparent crystallized, or what might be called the sapphire or gem varieties.

The various colors of corundum have been attributed to different chemical compounds that occur in it in traces or very small amounts; but as far as can be discovered from the examination of the analyses, there is nothing to indicate that the color is due to the presence of certain chemical components aside from the alumina in the corundum. On comparing various analyses, they are found to be very similar, their differences consisting of variations in the percentages of the several constituents rather than variation in the constituents themselves. In many of the corundum specimens, especially of the sapphire or gem variety, we find two, three, or more colors in the same specimen. It is probable that the various colors observed are not due to the influence of any trace of some chemical constituent in the corundum, but to some physical phenomenon.

In the following table a few analyses are given of both American and foreign corundums:

Analyses of Corundum.

Locality.	Al_2O_3	Fe_2O_3	SiO_2	H_2O	Insoluble Residue.	Total.	Analyst.
Hastings County, Ontario.	96.92	...	...	2.43	1.36	100.71	Wells.
Sapphire from India.....	97.51	1.89	0.80	...	...	100.20	Smith.
Ruby from India........	97.32	1.09	1.21	...	...	99.62	Smith.
Corundum Hill mine, N. C.	98.79	0.75	0.90	0.78	...	101.22	Emerson.
Laurel Creek mine, Ga...	95.51	0.88	1.45	0.74	...	98.58	Emerson.

In the above analyses the material used was pure and not commercial corundum, which contains, besides this mineral, varying quantities of other alumina and iron minerals. In analyzing a commercial corundum, the percentage of alumina found does not indicate the percentage of corundum in the sample, for all the other minerals, such as spinel, amphibole, pyroxene, chlorite, garnet, etc., that may be in the sample contain more or less alumina, and this would be included in the percentage obtained. To determine, therefore, the percentage of corundum in a sample, it must be directly separated from the rest of the minerals that are a part of the sample. A number of serious errors and misleading statements have been made regarding a commercial corundum, by estimating the amount of corundum by the percentage of alumina obtained in the chemical analysis. Such an estimate might rate the sample altogether too high. This mistake has been made in regard to emery from near Peekskill, N. Y., described on page 236. In this emery there is sometimes a larger percentage of spinel than of corundum, but in the chemical analysis of the commercial product the percentage of alumina would not be very much below a good emery, for the mineral spinel contains nearly 72 per cent of alumina. The abrasive efficiency of such an emery would be considerably lower than that of a true emery, as the cutting power of the spinel is much lower than that of the corundum.

DETERMINATION OF CORUNDUM IN AN ORE.

The following method has been used to advantage in the determination of corundum in an ore. The material is crushed in an iron mortar to pass through a 14-mesh sieve and sampled. Two grams of the material are taken and treated with concentrated hydrochloric acid on the water both for two hours. The residue is then filtered off, dried, and fused one-half hour with 6 grams of sodium carbonate mixture (two parts Na_2CO_3, one part K_2CO_3) in a platinum crucible over an ordinary Bunsen burner. The fused mass is extracted with hot water, and the solution decanted through a filter. The residue is treated with a large excess of dilute hydrochloric acid, and this solution is decanted through the same filter. The filter paper is dried and ignited in a platinum dish, the residue from treatment with hydrochloric acid is added to the dish, and the whole is treated with an excess of concentrated hydrofluoric acid. The excess of hydrofluoric acid is evaporated off on the water bath, the residue treated with hot water, and finally transferred to an ashless filter paper. This paper and contents are dried, and then transferred to a weighed platinum crucible. The paper is removed by ignition, the crucible cooled and weighed. The increase in weight (residue) is calculated as pure corundum.

VARIETIES OF CORUNDUM.

In the following pages, a more detailed description is given of the three principal varieties of corundum mentioned on page 164, together with their uses, which are very limited and can be divided into the two general heads, gems and abrasives. Under the sapphire variety the localities are also described, as there are but few of them; but under corundum and emery, no localities are described, as Chapter VIII is devoted to them.

SAPPHIRE OR GEM CORUNDUM.

As the terms "gem mineral" and "precious stone" are used at the present time, they apply to three classes of minerals: (1) those that are of value for cutting and use as jewelry and that are commonly called gems, as the diamond, ruby, beryl, amethyst, etc.; (2) those that are used after cutting or polishing for ornamental or decorative purposes, as quartz, jade, agate, malachite, etc.; (3) those that from their rarity and beauty are of ornamental and mineralogical value, as quartz crystals, pyrites, rhodochrosite, calcite, etc. As is very evident, these divisions so overlap one another that no sharp lines can be drawn between them.

The word gem is used ordinarily to designate any precious stone when cut or polished. In mineralogy the term is often used for a class of minerals whose hardness is over 7 (or harder than quartz) and that are without metallic luster and are brilliant and beautiful.

The properties of a mineral that determine its value as a gem are hardness, color, rarity, index of refraction, and luster. To illustrate how hardness affects the value of a mineral for gem purposes, sphalerite might be cited. This mineral, with an index of refraction and luster not far from that of the diamond, has a hardness of only 3.54, which effectually prevents it from being a gem mineral.

The term used to designate the weight of a gem is "carat," a carat being equal to 3.168 grains (this is the international carat) or 250 milligrams. This word should not be confused with the term carat that is used to measure the fineness of a gold alloy.

Some varieties of corundum have properties that place them among the most valuable of the gems. With the exception of the diamond it is the hardest mineral known and the rarity and color of the ruby, or red corundum, has made that gem, when over a carat in weight, more valuable than a diamond of the same weight. Corundum has been found in almost all the colors of the rainbow. The colors stated below are exhibited by the different corundum gems. With the name of the gem the prefix "oriental" is often used to distinguish it from gems of the same name whose mineral composition and character are entirely different:

Varieties of corundum gems.

Oriental or true ruby	Red and shades of red.
Oriental amethyst	Purple.
Pink sapphire	Rose or pink.
Oriental sapphire	Blue and shades of blue.
Opaline Girasol Hyaline	Pale blue or bluish white.
Oriental emerald	Green.
Oriental topaz	Yellow.
White sapphire Diamond spar	Colorless.
Star sapphire Chatoyant Asteria	Opalescent.

All these varieties of corundum gems have been found in North Carolina, the greatest number of them having been found at the Corundum Hill mine, Cullasaja, Macon County. The North Carolina corundum excels in variety of color, being found ruby-red to rose and all intervening shades, pink, sapphire-blue, dark blue to pale blue, emerald-green and various shades of green, violet to purplish, yellow of various shades, brown, gray, black, and colorless.

In index of refraction, corundum is lower than a number of the commoner gem minerals. In the following table the relative position of the corundum is shown:

Indices of refraction of gem minerals.

	Lithium (Li.) = Red.	Sodium (Na.) = Yellow.	Thallium (Tl.) = Green.	
Diamond	2.4135	2.4195	2.4278	Descloix.
		ω ε		
Zircon	.....	1.9236-1.9682	.....	....
Almandite (Garnet) ...	1.8000	1.8056	1.8113	Pratt.
Pyrope (Garnet)	1.7776	1.8141	1.8288	Descloix.
	ω ε			
Sapphire (Corundum) ..	1.7678-1.7598	.....	.....	Descloix.
Ruby (Corundum)	1.7675-.7592	.....	.....	Descloix.
Rhodolite (Garnet)	.....	1.7496	.....	Pratt.
Spinel ruby (Spinel) ...	1.7121	1.7155	.....	....
Hiddenite	.....	$\beta = 1.669$	.....	....
Topaz	.....	$\beta = 1.615$	.....	....
	ω ε	ω ε	ω ε	
Tourmaline	1.6347-1.6172	1.6374-1.6196	1.6409-1.6232	Pratt.
Emerald (Beryl)	.....	1.5841-1.5780	.....	....
Aquamarine (Beryl) ...	1.5862-1.5791	1.5893-1.5821	1.5921-1.5848	Dufet.
Amethyst	1.5391-1.5480	1.5441-1.5532	1.5542-1.5636	....

According to the above table corundum would rank fourth in the list of gems in respect to its index of refraction; but, as is well known, it is not its brilliancy but its rich pigeon-blood-red color and its luster that are so highly prized in the ruby, and that give to it its great value.

The next table shows the position of the corundum when the gems are arranged according to hardness:

Table showing hardness of various gems.

Diamond	10	Zircon	7.5
Sapphire	9	Rhodolite	7.5
Ruby	8.8-9	Pyrope	7.5
Spinel ruby	8	Almandite	7.5
Topaz	8	Amethyst	7
Emerald beryl	7.5-8	Hiddenite	6.5-7
Beryl	7.5-8		

The oriental ruby comes third in the table of hardness, but its rich color and its rarity have made it the most valuable of gems when it is more than one carat in weight, of the right color, and free from flaws.

The many uses that are made of the cut sapphire gems in the jewelry trade are too well known to need more than a passing notice here. One use of them that is perhaps worthy of notice is as jewels for watches. In a recent notice from the Swiss Agency of Precious Stones for Watches, Aarburg, Switzerland, it is said that 75,000,000 watch jewels were required annually. With the increase of production of gem corundum in this country, a great deal of the smaller fragments could and should be utilized in the manufacture of watch jewels.

Corundum of gem color has been found at many mines in the State, but it is usually translucent or only partially transparent. The gems occur in the mines, first, as crystals, of which there are two distinct forms, (1) hexagonal prisms terminated by rhombohedrons and pyramids, sometimes with basal plane, the larger crystals being often rounded or barrel-shaped, and (2) flat tabular crystals, in which the basal plane is very largely developed; second, as transparent colored portions of larger massive pieces of corundum; and third, as nodules of finer and clearer materials in a mass of corundum in which parting has been highly developed. The nodules when separated from the mass of corundum often have the appearance of rolled pebbles.

RUBY.

The most important of the precious stones of the corundum species is the ruby. The ruby varies in color from rose, pinkish, dark red, purplish, to pigeon-blood color, which is the most highly prized. Rubies are very likely to be flawed, and many of the cut stones when examined are found to contain flaws of one character or another. The stones are often so cut that these flaws are distinguishable only by the aid of a magnifying glass.

The finest rubies of pigeon-blood color are those found in the Mogok district, about 90 miles north-northeast of Mandalay, in upper Burmah. Small but fine rubies, often, however, of a pink color or a purplish tint, are found at Ratnapoora, in Ceylon; and of a dark red color, similar to that of a garnet, in Siam. The rubies of the Burmah district are found in place in limestones, but the mining is confined almost entirely to the gravels.

At the Corundum Hill (Cullasaja) mine, North Carolina (see description, p. 246), various shades of gem ruby corundum have been found. Two of the best rubies of good color that have ever been found at this mine are in the Bement collection. There are also a number of fine ones in the United States National Museum at Washington. Many of the smaller crystals of various shades of pink to red are transparent near the outer surface and near their extremities, from which small gems can be cut, but few, however, have been obtained from these that were worth $100. These smaller crystals are usually well developed and have clean-cut forms. The faces commonly developed on these are, the base, *c* (0001), the unit prism, *m* (10$\bar{1}$0), the unit rhombohedron, *r* (10$\bar{1}$1), and more rarely the pyramid, *n* (22$\bar{4}$3), see fig. 11, p. 165.

The largest crystal of corundum ever found is from this mine and is now in the cabinet at Amherst College. The crystal, as found in 1872 by Mr. Charles W. Jenks, weighed 312 pounds. The general figure is pyramidal, the unit prism being terminated by the pyramid and unit rhombohedron. The color of the crystal is red at the surface, but bluish gray in the interior.

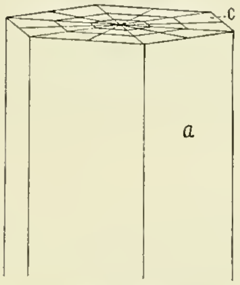


FIG. 15.—Corundum crystal from Corundum Hill, N. C.

The North Carolina locality for corundum gems that has attracted the most attention is the tract of land between the Caler Fork of Cowee Creek and Mason Branch, two tributaries of Little Tennessee River. This tract is situated in Macon County, almost 6 miles below (north of) the town of Franklin. The nearest railroad station is Dillsboro, Jackson County, on the Southern Railway, about 12 miles to the east. The bottom of the valleys is about 2,500 feet above sea level and the mountain peaks or knobs in the immediate vicinity rise to a height of 3,000 to 3,500 feet.

In the gravels of Caler Fork Valley pieces of crystals of red corundum were picked up by the people of the district, which led to the driving of two or three tunnels with the expectation of striking the vein and finding the corundum in sufficient quantity for abrasive purposes. Work in this direction was soon abandoned and for a number of years prospecting and a little mining were done for the red corundum for gem purposes. Systematic search was made, which revealed the fact that ruby corundum was to be found in the gravels of Caler Fork Valley for a distance of 3 miles. In 1895, the American Prospecting and Mining Company of New York bought out the old claims and began work on a systematic basis (Plate XVII, A and B). The property owned by the company is a large tract on both sides of Caler Fork of Cowee Creek and nearly all the land in the water shed of Mason Branch, an area of about 1,500 acres.

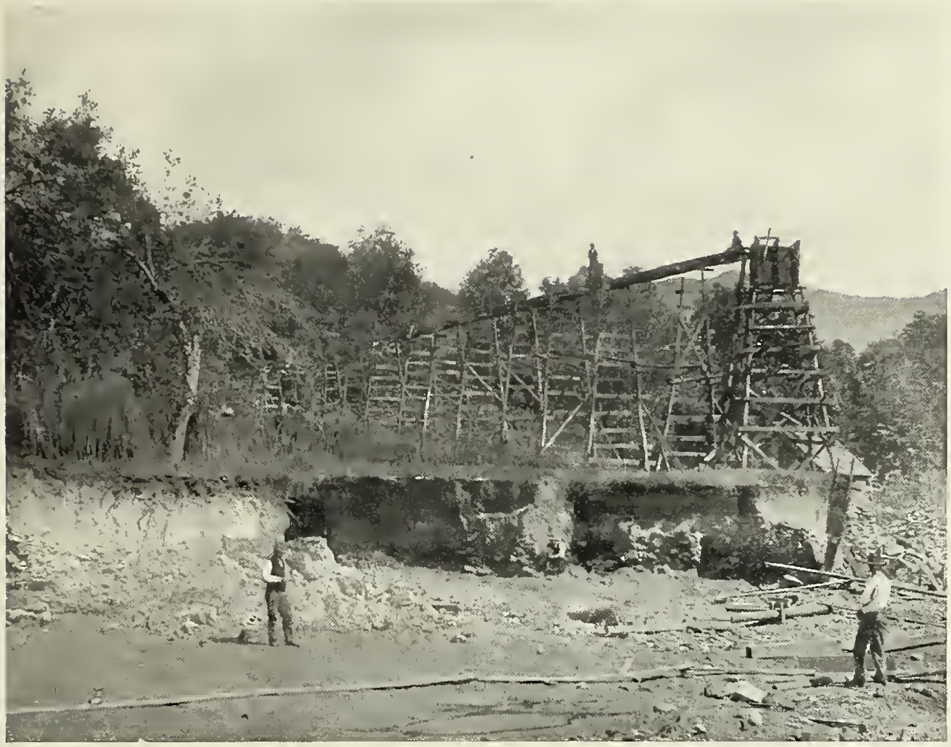
No basic magnesian rocks or serpentine derived from them, in which most of the corundum of North Carolina occurs, have been found in this valley. Corundum Hill and the Ellijay region are, however, less than 10 miles to the south.

Although in many respects the occurrence of the rubies and their associated minerals in the Cowee Valley is similar to the occurrence of the ruby in Burmah, no limestone has been found near the alluvial deposits. The nearest point at which limestone has been found is at Cullowhee Gap, about 8 miles to the southeast.

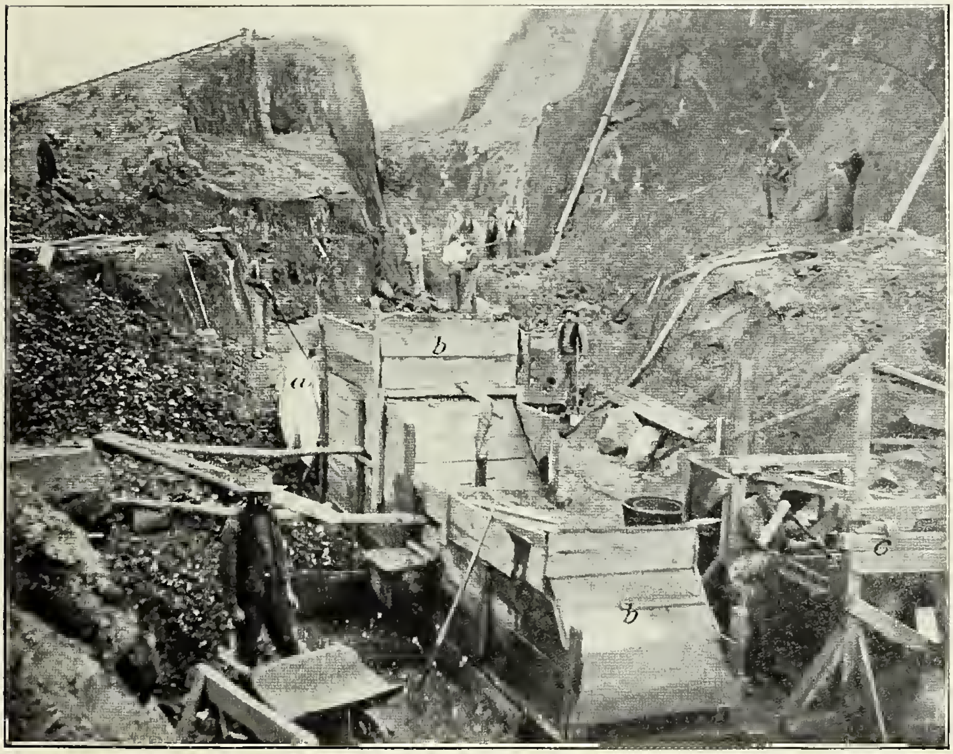
The country rock of the district is a gneiss, of a gray, fine-grained variety, through which is disseminated a great many small garnets. The rock is for the most part in a highly decomposed condition, but in many places there are small exposures of the undecomposed rock. The gravels in which the rubies are found rest on a soft saprolitic rock, which is the result of the weathering of acid silicate rocks in place. By means of shafts and the workings at the gravel washings, it has been shown that at depths of 35 feet or more these saprolitic rocks contain fragments of the undecomposed rocks and pass into various rocks, as eclogite, amphibolite, and hornblendic gneiss.

A narrow dike of hornblende eclogite, a few feet in width, is exposed near the present workings of the company, at "In Situ" Hill, and can be traced for several hundred yards.

No rubies have been found in the undecomposed rock, but at "In Situ" Hill small rubies of a rather pale color were found in a narrow band of saprolitic rock. This band, however, was cut off by slickensides so that it could not be followed in any direction. There are four parallel slickensides that have been exposed at one place in the workings, their general direction being N. 75° E. Some of these slickensides are 70 feet in length and of unknown depth. It is very evident that there has been a great deal of disturbance in this immediate vicinity and that the rock masses have been much broken by faulting, the ready influx of water having caused the reduction of the rocks to the saprolitic condition.



A, BED OF RUBY-BEARING GRAVEL AT CALER FORK, COWEE VALLEY, MACON COUNTY, N. C.



B, RUBY MINE AT COWEE VALLEY, N. C., WITH PLANT FOR WASHING THE GRAVEL IN THE FOREGROUND; (A) SLUICE BOXES; (B) SIEVE BOXES; (C) ROCKER.

In washing the gravels and saprolite, masses of undecomposed rock have been uncovered and in the center of these masses nodules of pure hornblende rock have been found. The saprolite bordering the nodules often contains particles and crystals of corundum.

Less than 2 miles east of "In Situ" Hill, beyond Betts Gap, corundum of a gray to bluish color but highly crystallized, has been found in hornblende gneiss (see p. 252); and one mile a little north of west at the Sheffield mine, pink corundum has been found in an amphibole-schist.

An associate of corundum that is unique to this locality is the garnet, rhodolite. They occur not only constantly together in the saprolitic material and in the gravels, but corundum crystals have been found that bear the impression of the garnet. By means of wax a mold was taken of these impressions that showed them to be either the dodecahedron or trapezohedron. Then again, some of the ruby crystals when broken are seen to have a garnet enclosed and the garnet can often be seen in the transparent ruby crystal and the cut gem. The association of the garnet and corundum are shown in fig. 16, which was drawn by Mr. W. E. Hidden.[12]

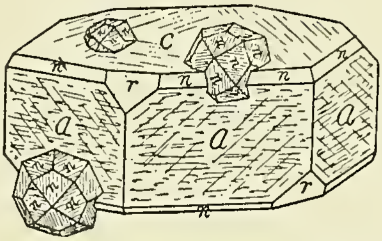


Fig. 16.—Association of garnet (rhodolite) and corundum crystals; from Caler Fork, Macon County.

As has been said, there is no limestone in this immediate vicinity and from the facts that can be obtained the source of these rubies is probably an amphibolite, or eclogite. The crystals are usually of flat tabular form—the form that seems to be characteristic of the gem corundum found in igneous rocks.

The Cowee Creek rubies frequently contain inclusions, some of which are very minute, known to jewelers as silk, and this gives rise to a cloudiness or sheen in the polished gem. Rutile and menaccanite often occur in the rubies, greatly marring their beauty and their value. Some large gems—3 or 4 carats in weight—have been cut which were free from inclusions and of fine color and transparency. A great many smaller perfect gems have been cut. In color and brilliancy these are equal to the Burmah ruby, and if the percentage of the unflawed transparent material increases but little, this new field for the ruby would be a well-matched rival to the Burmah fields.

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[12] Am. Jour. Sci., 4th ser., Vol. VIII, 1899, p. 376.

A considerable proportion of the transparent material is often very badly flawed by cracks due to parting, and by the inclusions of rutile, menaccanite, etc., so that the percentage of perfect stones from this mine is small. This, however, is true of the rubies from the Burmah fields, and a large percentage of the rubies that are on the market to-day are more or less flawed, usually with parting cracks.

The pleochroism exhibited by the Cowee rubies is very marked, some of them being a very rich pigeon-blood red in the direction of the vertical axis, that is, looking down upon the basal plane, and changing to an almost pinkish white color when viewed at right angles to this, or looking through the prism. The pleochroism which all the colored varieties of corundum gems exhibits is one of the means of identifying them. This, however, often interferes with the cutting.

The ruby crystals from the Cowee Valley show a wide variation in their development. Although many of the crystals are so striated that no crystallographic measurements were possible in the reflecting goniometer, the faces were readily identified by means of the contact goniometer. On some of the crystals the faces were bright and smooth, and therefore well adapted to measurement on the reflecting goniometer.

Among the crystals examined there were two common habits noticed, one as shown in figs. 1 and 2, Pl. XVI, which is a combination of the base c (0001) and the unit rhombohedron, r $(10\bar{1}1)$, the other, represented by figs. 3 to 6, Pl. XVI, where the prism a $(11\bar{2}0)$ is very prominently developed. The rhombohedral crystals vary from those where the base is largely developed, having a diameter of 12 mm. while the rhombohedron is only 1.5 mm. to some (fig. 1, Pl. XVI) which have the base and rhombohedron more equally developed. In the majority of these crystals, however, the base is more largely developed, so that the crystals have a flat tabular appearance. This rhombohedral development is very similar to that of the sapphires from Yogo Gulch, Montana.[13]

On some of the prismatic crystals the prism reaches a length of nearly 15 mm. in the direction of the c' axis, and the rhombohedron is but slightly developed (fig. 3, Pl. XVI), while on others the prism is very short and the rhombohedron sometimes is wanting, as represented in figs. 4 and 5, Pl. XVI.

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[13] Am. Jour. Sci., 4th ser., Vol. IV, 1897, p. 424.

Another habit of these crystals is shown in figs. 7 and 8 of Pl. XVI, where the pyramid *n* $(22\bar{4}3)$ is well developed. This face was identified by means of the contact goniometer, the measured angles approximating closely to the calculated ones. The usual form of these crystals is shown in fig. 7, Pl. XVI, where the faces *c* (0001), *a* $(11\bar{2}0)$, *r* $(10\bar{1}1)$, and *n* $(22\bar{4}5)$ are nearly equally developed. On some of the crystals the prism is very prominent, being 8 mm. in length in the direction of the *c*′ axis, while the pyramid is only 1.5 mm.; on others the pyramid is only very slightly developed. A few crystals were examined which showed only the presence of the base, the rhombohedron, and the pyramid, as represented in fig. 8, Pl. XVI. The crystals, measuring up to 7 mm. in diameter, were doubly terminated and nearly perfect in their development.

The crystals represented by fig. 7, Pl. XVI, are similar to those described by Bauer[14] from the Burmah district, and are almost identical in form with a sapphire crystal observed[15] from Emerald Bar, Canon Ferry, Magher County, Montana.

Although both the basal and rhombohedral planes are very often striated, it is only on the basal planes that these are sharp and distinct and can be measured. The striations are parallel to the three intersections of the base *c* and the rhombohedron *r* as shown in fig. 5, Pl. XVI.

A very common development that was noticed in nearly all the flat rhombohedral crystals and on many of the prismatic ones is a repeated growth on the basal plane of the rhombohedron *r* $(10\bar{1}1)$, and the base *c* (1001), as represented in figs. 1 and 6, Pl. XIV. To better illustrate the variation in these growths, a series of figures, figs. 9 to 14, Pl. XVI, have been drawn in basal projection. In figs. 9 and 10, Pl. XVI, which represent the more common development of these repeated growths, there is but one secondary rhombohedron and base, one of the rhombohedron faces of which is sometimes a continuation of one of the rhombohedral faces of the crystal. Figs. 11 and 12, Pl. XVI, represent repeated growths the faces of which are separate and distinct from one another and from the faces of the main crystal. In the crystals represented by fig. 12, Pl. XVI, where the secondary growths are but slightly developed, the basal plane of the crystal has the appearance of being striated with triangular markings. Figs. 13 and 14, Pl. XVI, show a series of growth with a number of the rhombohedral faces coinciding.

Some of the pyramidal crystals figs. 7 and 8, Pl. XVI, also show the development of the secondary growth of rhombohedron and base.

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[14] Neues Jahrb. für Min. Geol. und Pal., Vol. XI, 1896, p. 209.

[15] Pratt, Am. Jour. Sci., 4th ser., Vol. IV, 1897, p. 427.

The thickness of the rhombohedron of the secondary growth varies from those that are so thin that they appear like striations to some that are 2 mm. thick. A few crystals were observed on which there was a secondary growth parallel to the prism, $11\bar{2}0$.

This same style of development has been described by Bauer[16] as occurring in the Burmah rubies.

The sapphire crystals from Montana described on page 187, and illustrated in Plate XVIII, are very striking in their similarity in this respect to the Cowee rubies.

Much of the work that has been done in the valley has been in the nature of prospecting to locate the extent of the ruby-bearing gravel and, if possible, to locate the origin of the rubies themselves.

At the Mincey mine, Ellijay creek, ruby corundum has been found from which several small stones could be cut. This occurs at the same locality as the bronze corundum described on page 189. Another locality that is worthy of mention and one that gives some promise in course of development to make a good showing is the "Gem mine" on the property of Dr. C. Grimshawe, Montvale, Jackson County. Rubies of good colors have been found in the gravels of the stream, from which a number of fine but very small stones have been cut. Blue and yellow corundum of good color are associated with the rubies. Following up the gravels, the corundum has been located in a small vein in the decomposed peridotite.

At the Cullakeenee mine, on Buck Creek, and near Elf, on Shooting Creek, Clay County, masses of emerald to grass green amphibolite are found, through which are disseminated particles of pink and ruby corundum, in size varying from that of a pea to that of a hickory nut, and sometimes broad tabular masses 2 or 3 inches across. The corundum is not of real gem quality, but the combination of the green amphibolite and pink corundum make very beautiful specimens, and as this rock is hard enough to take a good polish, it should make a decorative or ornamental stone of some value.

SAPPHIRE.

The finest sapphires are found in Burmah and Ceylon; and those with the finest corn-flower blue color have also been obtained from Ceylon. Simla Pass, in the Himalaya Mountains, has furnished some excellent crystals of a rich velvety blue and also some very good stones of a lighter color. Sapphires that have made very good gems have been found in Siam. In the sapphire fields of Anakie in Central Queensland, Australia, a few good blue stones are obtained but the greater number are of bright green and yellow shades, some of which make handsome gems.

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[16] Loc. cit., p. 209

The Montana sapphires, which have been attracting considerable attention during the past five or six years, occur at three localities in the State. The locality that was first discovered is on the Missouri River, about 61 miles above Benton and 17 miles northeast of Helena. Here the sapphires are obtained from bars in the river. There are a number of these bars, which occur in the river for a distance of about 6 miles, and which are known by various names, as Emerald Bar, Ruby Bar, Spokane Bar, Eldorado Bar, etc.

At another locality, on Rock Creek, in Granite County, sapphires of all colors have been found in the gravel, and this is one of the more promising localities in the State.

But few gems of any great value have, up to the present time, been found at either of these localities. The stones have a wide range of color, those from the Missouri bars being pale blue, pinkish blue, bluish green, pink, and purplish. Some of these have cut very brilliant stones. The deep shades of the blue are rare, but a few stones have been found that furnished small fine gems.

The third locality, Yogo Gulch, is on the Yogo Fork of the Judith River, about 75 to 100 miles east of the region first named. The rock in which the sapphires have been found is a monchiquite (see p. 225). At this locality many handsome sapphires are being obtained, the colors varying from a light blue to dark blue.

The crystals from the Missouri River and Rock Creek localities are entirely different in their development from those from Yogo Gulch. Those from the Missouri River bars (Emerald Bar) have the forms shown in fig. 9, and figs. 4 and 7, Plate XVI, the prism a $(11\bar{2}0)$, being always present and usually in combination with the base c (0001) and the unit rhombohedron, r $(10\bar{1}1)$. Those from Yogo Gulch are more flat and tabular in their development, as shown in figs. 1 to 4, Pl. XVIII, where the base is in combination with the rhombohedron, x $(30\bar{3}2)$. A common development of these crystals, which is very similar to that described for the Cowee rubies, is the repeated growth on the basal plane of the rhombohedron, x $(30\bar{3}2)$, and the base, c (0001). These growths are as varied as those on the rubies and are represented in figs. 11 to 14, Pl. XVIII, where they are drawn in basal projection.

Etching figures were observed on nearly all the crystals examined from Yogo Gulch.[17] These figures, which were on the basal plane, are very perfect and, though showing many different forms, all have a rhombohedral symmetry. The edges of the depression are sharp and well defined, as are also the intersections of the rhombohedral faces of the depression. These vary considerably in size, but most of them are near one millimeter in diameter, Pl. XVIII, figs. 5 to 10.

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[17] Am. Jour. Sci., Vol. IV, 1897, p. 425.

Bauer[18] has described similar etching figures on the basal plane of the rubies of Burmah.

No locality in North Carolina has furnished very many sapphires and at none is the corundum distinctly of the sapphire variety. At the Corundum Hill (Cullasaja) mine, a number of very handsome specimens and gems have been obtained. In the U. S. National Museum at Washington there are a number of fine dark blue sapphires from this mine, one of 1 carat in weight. The Leidy collection contained three fine sapphires from this mine weighing one and one-half, one and one-fourth, and three-fourths carats respectively. There are also a number of fine blue and red crystals in the collection. The same specimen often shows yellowish and blue colors, sometimes sharply separated into consecutive bands, sometimes merging into each other. A beautiful crystal of blue and yellow corundum in consecutive bands, from which it has been estimated that $1,000 worth of gems could be cut, is in the Clarence S. Bement collection, in the Museum of Natural History, New York City. A large crystal that is in the Amherst College Museum weighs 11¾ pounds and is of a grayish blue color, with spots of a pale sapphire tint. The crystal has the hexagonal pyramid well developed and is terminated at one end. It is 6 inches broad and a little over 5 inches long. A great many of the corundum crystals are transparent near their extremities, where small gems could be cut from them.

At the Sapphire Corundum mines, in Jackson County, some fragments of sapphire of fine blue color have been found which have cut good gems. At the Whitewater and Sapphire mines, considerable of the corundum is spotted with blue.

Associated with the green amphibolite rocks near Elf post-office, Clay County, blue corundum has been found sparingly, having the same relation to the rock as the red and pink corundum described on page 186.

Four miles east of Franklin, Macon County, on the Dillsboro road, at the Watauga mine of the National Abrasive Manufacturing Company, all the corundum mined was in the form of flat tabular or short, prismatic crystals. The color of the crystals was pale blue and pinkish to whitish blue and many were transparent. None were observed that showed a deep blue color.

At the Presley mine, on the west fork of Pigeon River, in Haywood

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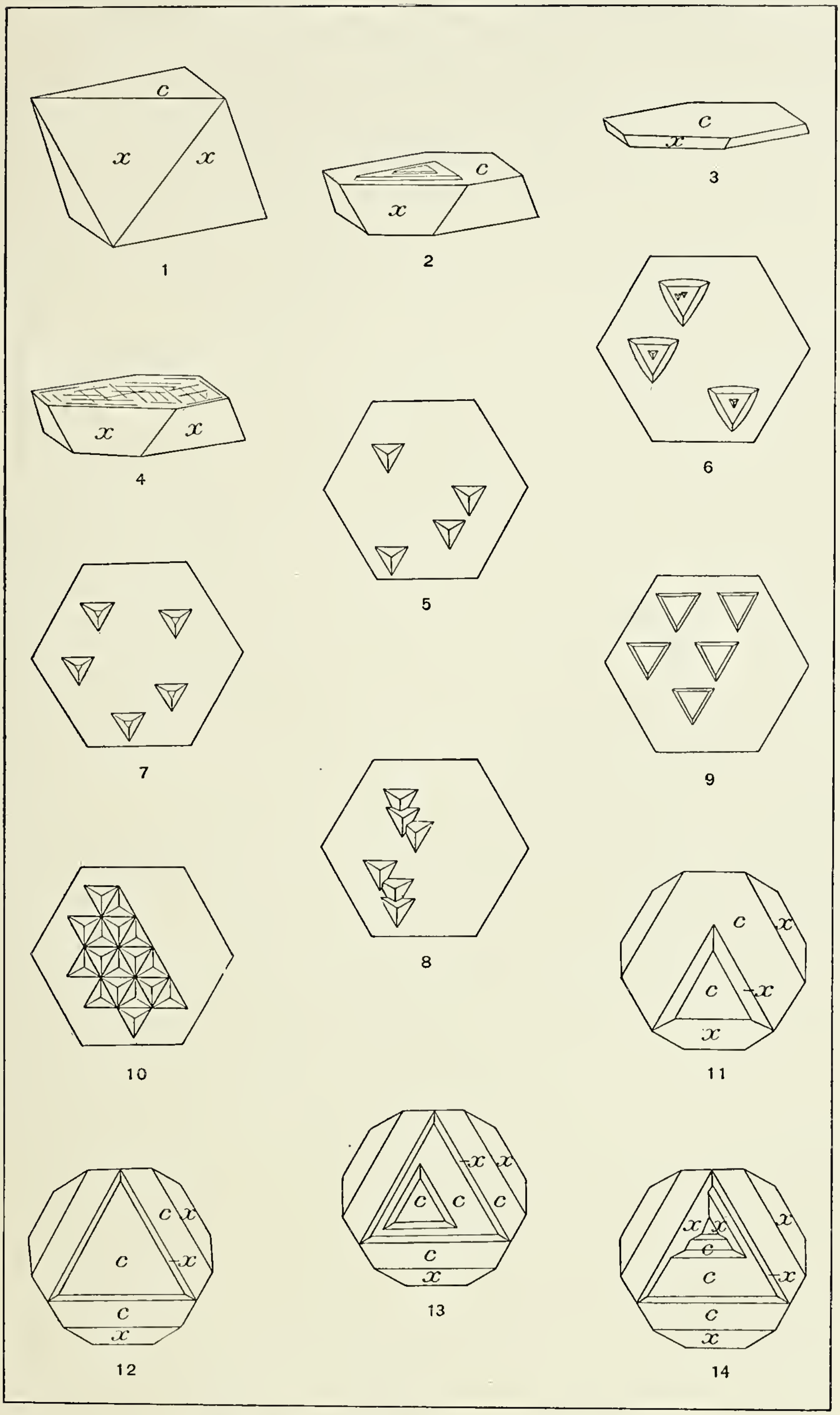
[18] Neues Jahrbuch für Min. Geol. und Pal., Vol. II. 1896, p. 213.



CRYSTALS OF CORUNDUM FROM YOGO GULCH, MONTANA.

County, fine colored specimens of blue and grayish blue corundum are found.

Small blue crystals in fibrolite have been found at Norwich, Connecticut. At Vernon, New Jersey, blue and red corundum have been found, but usually showing no transparency. Some of these stones have been cut, but it is not probable that any of them were of gem quality.

In the deep blue sapphires the pleochroism is often very strong, and care must be taken in cutting the stone to show this at a minimum.

EMERALD (ORIENTAL).

The emerald-green sapphire or the oriental emerald is one of the rarest of corundum gems and there are but very few if any on the market at the present time. Some, but of rather deep color, have been found in Siam.

At the Corundum Hill (Cullasaja mine), many specimens showing various shades of light green and yellowish green have been found, some of which were transparent. What is probably the finest known specimen of the oriental emerald in the world came from this mine and is now in the Bement collection. It is a crystal, 4 by 2 by 1¼ inches, part of which is transparent, from which could be cut several pieces that would furnish from 80 to 100 carats of very fine emerald-green gems, the largest perhaps about 20 carats in weight. This specimen, on account of its color, is a very valuable and rare one. No green corundum has been observed at any of the other corundum localities in North Carolina.

OTHER VARIETIES.

Besides the above three varieties of corundum gems, the Corundum Hill mine has furnished specimens of all the different corundum gems mentioned on page 178, with the exception of the star sapphire. Some very fine but small oriental amethysts have been found, one a violet to a violet-blue color of a little over one carat in weight. Transparent yellow corundum has been obtained, and this has furnished a number of handsome oriental topazes, one of a wine-yellow color that weighed 3¼ carats. Most of these fancy varieties of corundum gems are found in the Ceylon district.

At the Mincey mine, on Ellijay Creek, Macon County, about 2½ miles northeast of Corundum Hill, there occurs a peculiar brown to "bronze" corundum (known in this section as pearl corundum) which shows distinct asterism, both by sunlight and artificial light, when the stone is cut *en cabochon*. In sunlight they all show a bronze luster and are somewhat similar to the cat's eye, but in artificial light the star is more distinct, showing that the stone is the asteria or star sapphire, rather than the cat's eye. Most of this bronze corundum is in rough crystals, but some have the prismatic faces smooth and well developed. The prismatic faces are often dark, almost black, in color. The same variety is found at the Hunter mine in Iredell County.

This asterism is sometimes produced, according to von Lasaulx,[19] by the rifts due to the basal parting. The lamellæ produced by this, when examined under the microscope, are seen to be very thin, sharp and rectilinear, and appear as striations on the sides of the prism (fig. 14).

In other cases, asterism is undoubtedly due to the rutile or other minerals that are enclosed in the corundum, which intersect each other at angles of 60° and form a "sagenite web" or similar structure. Such corundum might well be called "sagenite corundum," similar to the sagenite quartz.

The Laurel Creek mine, Pine Mountain, Rabun County, Georgia, while it has not furnished any material from which gems could be cut, has produced some of the handsomest specimens of corundum, of various shades of blue and red and having a very brilliant luster. From the Acworth mine, Georgia, a peculiar banded variety of corundum is obtained of blue and pink colors.

Many of the other corundum mines have furnished specimens that were of a pink or blue color or had spots of the deep colors in the mass, but none of them have been of gem quality.

The most promising localities for corundum gems in North Carolina are the Ruby mine, at Cowee, Macon County; the Corundum Hill mine, Macon County; and the Grimshawe mine, Jackson County.

Of the gem corundum crystals and fragments found at the Corundum Hill mine, the first and many of the latter ones were found in the gravel of the old stream bed. Since 1873, when the work at the mine was for a time suspended, but little effort has been made to obtain the gems that do undoubtedly exist. Although it has not paid to work the mine exclusively for gems, yet in connection with the mining of the corundum for abrasive purposes, if some attention were given to washing the gravels and working that part of the mine in which the good crystals of gem quality have been found, it seems very probable that more gems and crystals would be obtained, which would make a profitable output of the mine.

COMMON CORUNDUM.

The varieties that are brought under this head are, with the exception of emery, all those that cannot be used as gems. As a commercial product there are differences, such as texture, purity, etc., that considerably affect the value of the material, in the same way that color and transparency affect the value of gem corundum. All the corundum except emery that is used as an abrasive comes under this head. While the hardness of the pure corundum is practically the same, that is 9, the cutting qualities of corundums vary, as has already been stated, according to the extent that alteration has taken place and to the development of the parting. The usual colors of the corundum included under this head are gray to white, shades of blue, and white mottled with blue, and also the darker colors, brown to black.

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[19] Zeitschr. für Krys., Vol. X, 1885, p. 351.

This parting, which has already been described, is often very prominently developed in corundum, so that where it is massive it has the appearance of being divided into very small, almost cubical blocks; and where this parting is very considerably developed, it materially affects its commercial value.

As the corundum occurs in the various veins it is classified by the miners as (1) block corundum, (2) crystal corundum, and (3) sand corundum. These three varieties of corundum, which are present at the different mines, are sometimes all three found in the same mine, as at Corundum Hill, although not all three are found in the same vein.

BLOCK CORUNDUM.

This variety constitutes the massive corundum as it occurs in the veins, whether in very small or large masses. A mass of block corundum weighing over 5,000 pounds is reported to have been taken from the Laurel Creek mine, Rabun County, Georgia. This mine has probably furnished the largest blocks of corundum. In some of the veins the block corundum is often intermixed with feldspar or hornblende or margarite or chlorite, or other minerals, so that the separation of the corundum from the foreign minerals is a rather difficult process. Corundum that occurs in masses of considerable weight is often very difficult to mine, on account of its toughness, as it is not readily broken up and cannot be drilled through. Block corundum that shows but little development of the parting planes and no intergrowth of chlorite in any cracks or seams that may have developed makes the best commercial corundum, and the difficulty of cleaning it is reduced to a minimum. Corundum showing pronounced parting planes is not easily cleaned, for these, as was stated on page 169, represent solution planes, and therefore more or less decomposition.

CRYSTAL CORUNDUM.

Under this head is included all the crystalline varieties of corundum, and this is often present in the veins of both sand and block corundum.

At many of the localities the crystals show the hexagonal prism merging into the pyramid, thus causing the crystal to assume a barrel-like appearance as it tapers toward the end, and it is therefore known as "barrel corundum." At a number of mines are found loose tapering crystals of rather indefinite form, enclosed by compact margarite. At many of the veins the crystals occur in a mass of chlorite which, if they show no parting planes, have but a small surface coated with the chlorite, so that in cleaning the crushed product there is but little foreign material to be ground away.

SAND CORUNDUM.

This corundum consists of minute crystals and small, irregular grains which are found in the chlorites and vermiculites developed in the contact veins between the peridotite and other country rock. Sand corundum requires no crushing, only washing and grinding off the chlorite and vermiculite that are attached to some of the particles.

EMERY.

As was stated on page 164, emery is a mechanical mixture of corundum and either magnetite or hematite, and its value as an abrasive is due to the percentage of the corundum it contains, for it is to this mineral that the emery owes its cutting qualties. This mixture of the corundum and the hematite or magnetite is usually so intimate that no separation on a commercial basis can be made, so that an emery could never be used as a source of corundum. When very finely crushed the iron oxide can be separated from the emery by means of an ordinary or electro-magnet. When examined under the microscope the two minerals can be seen distinctly. Sometimes the corundum is coarse grained, and it has been found at Chester, Mass., in crystals nearly half an inch in diameter.

In appearance emery is very similar to a fine-grained iron ore, and when it contains iron oxide (Fe_3O_4) it is almost identical in appearance with magnetic iron ore, magnetite. The color is blue black to black. When emery was first discovered it was mistaken for an iron ore and a number of attempts were made to work the deposits as iron ores. The largest American deposit, which is located at Chester, Mass., was first thought to be magnetic iron ore, and blast furnaces were erected to smelt it. but at the first attempt the furnaces became clogged up and were unable to reduce it to iron. The mine remained idle for a number of years until Dr. H. S. Lucas bought it and began to operate it as an emery mine. This mine, which is now owned and worked by the Ashland Emery and Corundum Company, and those at Westchester, N. Y., produce all of the emery that is mined in this country.

Emery is usually evenly fine-grained, but there are transitions from this to some kinds in which the corundum is in distinct crystals, as at the Chester mine. It usually occurs as nodules, or rough fragments, and large irregular masses. On account of its fine-grained texture, these larger masses are very difficult to break. They are broken in the same way as are large masses of corundum, that is, fires are built over them and when they are thoroughly heated, they are suddenly cooled by pouring water over them, this primitive method being very effective in breaking up these large masses.

Sometimes spinel is associated with emery and in some cases the spinel is largely in excess of the corundum and the mineral passes over into what might be called a "spinel emery." This is well illustrated at the Westchester mines in New York State, and in some of the emeries from the Grecian Islands.

Emery is sold in the market under the head of Turkish, Naxos, Chester, and Peckskill emery, according to the locality from which it is obtained. It was first obtained from certain Grecian islands, the principal one of which is Naxos, upon which there have been 17 deposits of emery located. The mines of Naxos for a long time controlled the emery market, until the important explorations of Dr. J. Lawrence Smith disclosed large deposits in Asia minor. By these discoveries a new source of emery was found which at once reduced the price. The best Turkish emery is thought to be that from the Abbot mine, which is considered by many to be better than that which is obtained from the Grecian islands, known as the best Naxos emery. The emery from Chester, Mass., which was at one time considered not to be a true emery, has taken its place with the Naxos and Turkish emeries, and is considered by many to be equal if not superior to these. For a description of these foreign emeries, see page 267.

USES OF CORUNDUM AND EMERY.

Both corundum and emery are used in the manufacture of abrasive materials, and these are on the market in three forms, as wheels and stones of various shapes and sizes, as emery paper, and as grains, or powder. The last two need no further description; but a description of the first is important.

The shapes of the corundum and emery wheels and bricks or stones, are varied, the forms being adapted to all kinds of grinding (see figs. 17 and 18). The principle of these wheels is the same as that of rotary files and common grindstones, and as the points of a file become dull from use, so also do the grains or points of the emery and corundum in the wheel. It is necessary, therefore, in making a wheel, that it be made of such temper or grade that when these grains become dull or rounded they will fall away or be readily removed by a truing tool, leaving fresh, sharp ones exposed. The grade of the wheel depends upon the character of the work for which it is to be used, and the bond—the material that binds the abrasive together as a wheel—should be such that it will wear away a little faster than the emery or corundum, and thereby always leave the sharp edges ready for cutting. The greatest economy is attained when the bond does not wear away until the grains of emery or corundum have become rounded or dull, thus permitting the wheel to do its greatest amount of work.

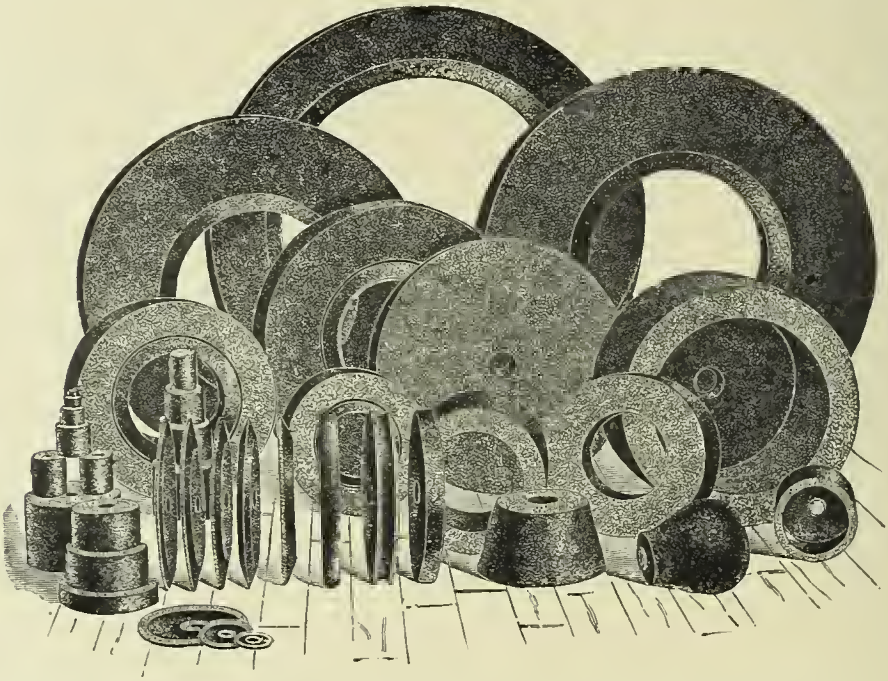


FIG. 17.—Various forms of products manufactured from corundum and emery.

All wheels are, or should be, thoroughly tested before leaving the factory, and to a higher strain than that to which they are to be subjected in actual use; and as the wheels have to be run at a very high velocity in order to gain the greatest efficiency, there is at times but little reserve strength, so that a sudden blow will often cause them to fly to pieces. Safety devices of various types have been made, which are either attached to the wheel, or made into the wheel in such a way that if the wheel breaks the pieces are held together.

To give some idea of the number of different wheels that the larger emery wheel companies are prepared to make, the following has been compiled from a communication received from the Norton Emery Wheel Company, of Worcester, Mass. The wheels are manufactured for the special work for which they are intended, and vary in shape, bond, and grain of corundum. The sizes of corundum that are used are Nos. 12, 14, 16, 20, 24, 30, 36, 40, 50, 54, 60, 70, 80, 90, 100, 120, 150, 160, 180, 200, and six grades of fluor corundum. Then the bond varies in hardness, represented by the twenty-six letters of the alphabet, though a bond is seldom used softer than E; and there are 408 different sizes of circular wheels. Thus the different grades and types of wheels possible are almost unlimited. Besides the circular wheel, they are molded into all kinds of shapes, making it possible to utilize them for practically any kind of grinding. In figs. 17 and 18 there are represented some of the different shapes and sizes of these wheels and stones.

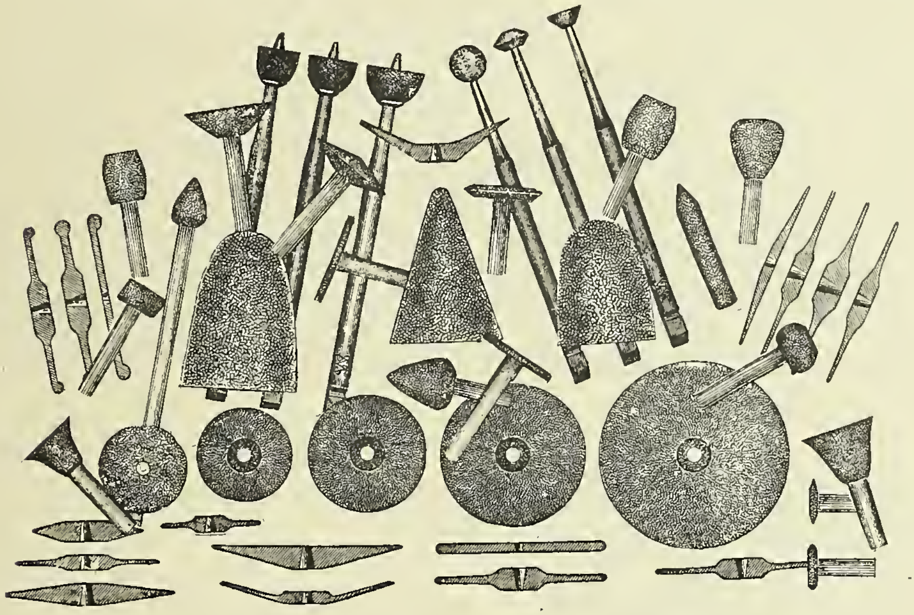


FIG. 18.—Dental appliances manufactured from corundum and emery.

There are three types of wheels known to the trade, the vitrified, the chemical, and the cement wheel, the names being derived from the process by which they are manufactured. The corundum or emery used in the manufacture of any one wheel is in grains of uniform size, but the size of grain varies with the grade of the wheel that is to be made. The vitrified wheel is the most important and the one most generally used, although for some work one of the others is preferable, and for very large operations the chemical wheel is especially adapted.

THE VITRIFIED WHEEL.

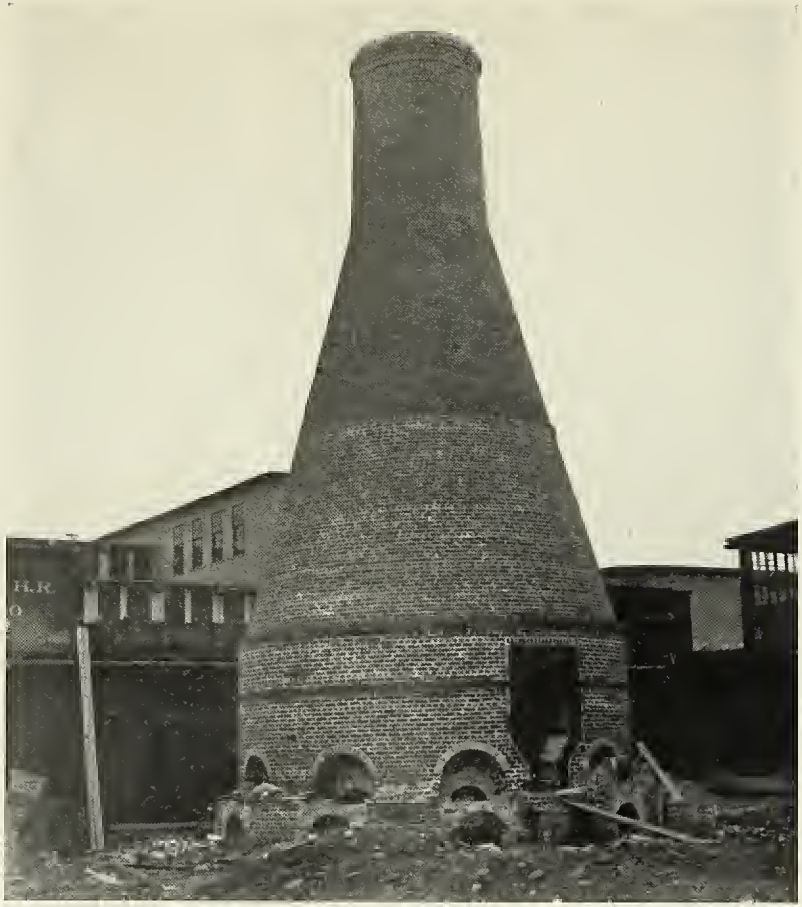
In the manufacture of this wheel great care is necessary in the selection of the corundum, for in the vitrification of the bond, if there are any foreign minerals present containing any large amount of water, they are very likely to cause the wheel to burst, and any that fuse easily will reduce its abrasive efficiency or destroy it altogether.

The corundum grains are mixed thoroughly in a paste of prepared clay and other fluxes, enough being added to make it the right constituency, and it is then poured into paper molds and set aside in a drying room until hard enough to be readily handled. When the wheels are sufficiently dry they are subjected to a dressing or trimming process and shaped to approximate dimensions on a potter's wheel or shaving machine and are then further dried. The excess of mechanically mixed water having been evaporated off, they are then ready for the kilns. The kilns are cone shaped (see A of Pl. XIX), and their inside measurements vary from 12 to 20 feet in height and 10 to 18 feet in diameter (see B of Pl. XIX). When the kiln is filled the entrance is closed and sealed and the fires are started. The temperature is allowed to rise but slowly, until all the water of mechanical admixture and of crystallization in the foreign materials (see p. 175) is driven off, when the temperature is raised to about 3,000° F. or to a white heat. This heating process requires several days. When the foreign minerals mixed with the corundum contain water of composition that is only driven off at a very high temperature, the wheels are apt to be broken by this water coming off when the temperature of the kiln is raised rapidly to the fusing point of the clay. The clay and other fluxes fuse and form a porcelain setting for each grain or fragment of corundum, which makes a very strong bond. The kilns are allowed to cool very slowly, a number of days being required for this. The kiln is then opened and the wheels are brought to a lathe, called the "truing machine," where they are turned to the exact dimensions desired, the hole is bushed to the exact size and the wheel is then trued and balanced ready for shipping.

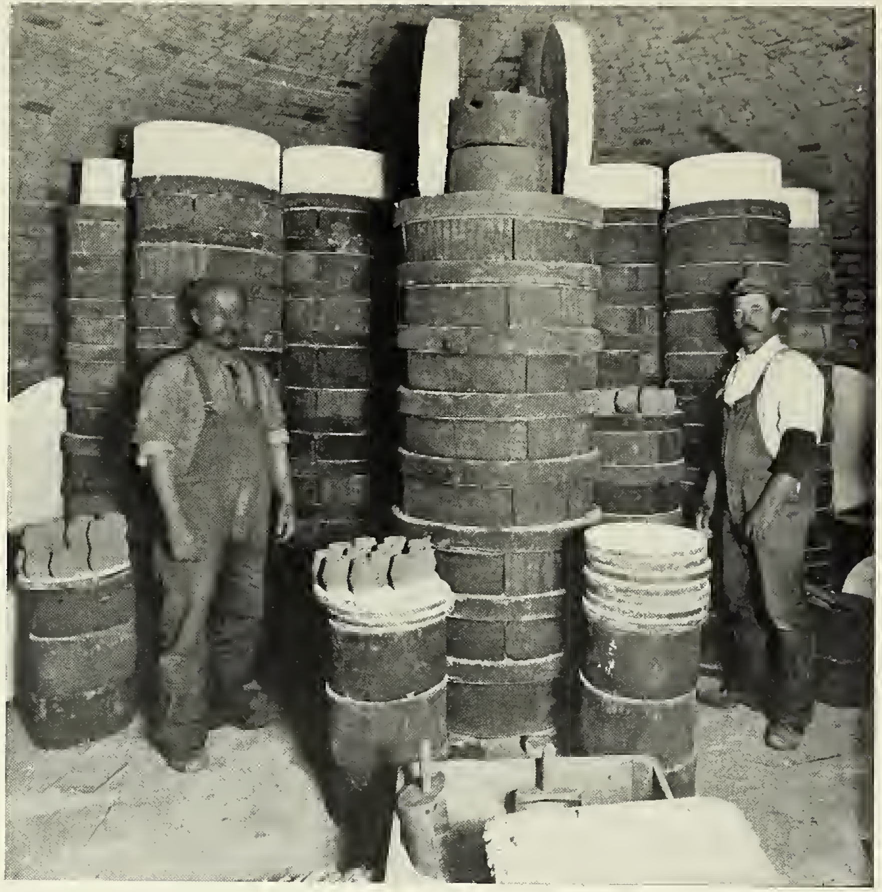
The heat necessary for the fusion in making the vitrified wheel apparently has no effect upon the corundum beyond a partial decolorization and the expulsion of the slight percentage of water it sometimes contains.

THE CHEMICAL WHEEL.

This wheel is manufactured by what is called the silicate process, silicate of soda being used as the binding material. The silicate is thoroughly mixed with the emery or corundum and with some drying ma-



A, EXTERIOR VIEW OF KILN USED IN VITRIFYING EMERY WHEELS AND STONES.



B, INTERIOR VIEW OF KILN, PARTIALLY FILLED WITH EMERY WHEELS AND STONES.

terial and stamped into molds. It is then subjected to an "oven" heat for twenty-four hours, after which it is removed and finished according to the method described above for the vitrified wheels after their removal from the kilns. Wheels have been made by this process that were over 2,000 pounds in weight.

THE CEMENT WHEEL.

In making the cement wheel, shellac, rubber, linseed oil and other substances are used as the binding material. This makes a soft wheel that is well adapted for roll and surface grinding, when made with shellac, and for saw gummers and thin wheels when made with oils.

AVAILABILITY OF CORUNDUM FOR WHEEL MANUFACTURE.

Although an examination of a corundum property may show the existence of considerable quantity of the mineral, no mining should be undertaken until satisfactory tests have been made of the corundum to prove that it has those properties that will make it of value as an abrasive.

The value of a corundum deposit as an ore for abrasive purposes depends upon that property of the mineral which enables it to retain a sharp edge, known as a cutting edge, when it is crushed to grains. All corundums do not have this property, and though many exhibit it in the first stage of crushing, their finer fragments and grains do not. This is more apparent when the corundum has been made into a wheel, for, when first used the wheel may do good work (especially if it is a coarse-grained wheel), but as it wears away, the grains of corundum, instead of breaking to a cutting-edge, become rounded. In estimating the value of a corundum deposit it is therefore very important to determine its abrasive qualities. Neither a superficial examination nor a chemical analysis of a corundum ore is sufficient to determine its cutting qualities, which can be ascertained only by making the corundum into a wheel and testing this.

In estimating the value of an ore it is also necessary to determine to what degree of purity it can be cleaned, or what percentage of the commercial product will be corundum, and also what will be the nature of the foreign minerals. No matter what the foreign mineral may be, it will be softer than the corundum and it will to a certain extent reduce its abrasive powers, but beyond this, the presence of a small percent does not materially effect the value of the corundum for making a cement or chemical wheel, but is often the reason for discarding it for the manufacture of a vitrified wheel, on account of the low fusibility of the foreign substance. Garnet is perhaps the most objectionable material in a corundum ore, for it is practically impossible to separate it from the corundum, as the specific gravity of the two is nearly the same. Then, again, any commercial corundum, containing even but little garnet cannot be used in the manufacture of the vitrified wheel.

OTHER USES OF CORUNDUM.

An attempt has been made to use corundum as a source of aluminum, but on account of its refractoriness, the percentage of ferric oxide and silica that it is apt to contain, and more especially on account of the cost of the ore, it has not been found feasible to use it for this purpose.

Mr. Alfred E. Hunt,[20] of Pittsburgh, Pa., who is connected with the Pittsburgh Reduction Company, has made the following statement:

> The real difficulty which we find in the use of corundum for this manufacture is the cost of the raw material as compared with that of native bauxites. In this item we include not only the price of corundum as it has been offered to us, but also the expense of grinding it to an impalpable powder, which must be done before it can be used directly in the manufacture of aluminum, and the cost of preliminary chemical treatment for putrification—which latter operation, however, is also required for bauxite. .

Corundum has also been used as the source of aluminum in the manufacture of aluminum-copper and aluminum-iron alloys. In the manufacture of these the corundum, without undergoing any previous treatment, was charged into an electric furnace with a mixture of carbon and copper or carbon and iron, according as aluminum bronze or ferro-aluminum was desired. Since 1890, however, when alumina began to be manufactured at a comparatively low price, this artificial oxide has been used in the place of the corundum.

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[20] Trans. Am. Inst. Min. Eng., Vol. XXVIII, 1898, p. 875.

CHAPTER VII.

MODES OF OCCURRENCE OF CORUNDUM.

A generation ago corundum was regarded as a comparatively rare mineral, that occurred abundantly, with the exception of the emery variety, only in the basic magnesian rocks, such as the peridotites and their serpentine derivatives; now it is known to occur in quantity in syenites and other igneous rocks, as well as in various gneisses and schists. It has been found in many crystalline rocks, and in some of them as an original mineral, but it is only within the past few years that it has come to be regarded as an essential rock-constituent; as in the syenites of Ontario, Canada, and in similar rocks in California, Montana, and other regions. In some cases it is undoubtedly a product of metamorphism.

Descriptions of its various modes of occurrence are given below, and some of these are discussed in Chapter X, in connection with the question of origin of corundum. The descriptions are given in the following order: (1) Modes of occurrence in North Carolina; (2) other occurrences in America; (3) modes of occurrence not found in America.

MODES OF OCCURRENCE IN NORTH CAROLINA.

At the present time corundum is known to occur in North Carolina in the following rocks, descriptions of which follow in the order given. The localities referred to are indicated on the map, Pl. II.

Corundum-bearing rocks in North Carolina.

Igneous.

Peridotite.
Pyroxenite.
Amphibolite.
Anorthosite.
Pegmatite.

Metamorphic.

Serpentine.
Gneiss.
Mica-schist.
Quartz-schist.
Amphibole-schist.
Chlorite-schist.

Alluvial.

Gravel deposits.

Undetermined.

Emery.

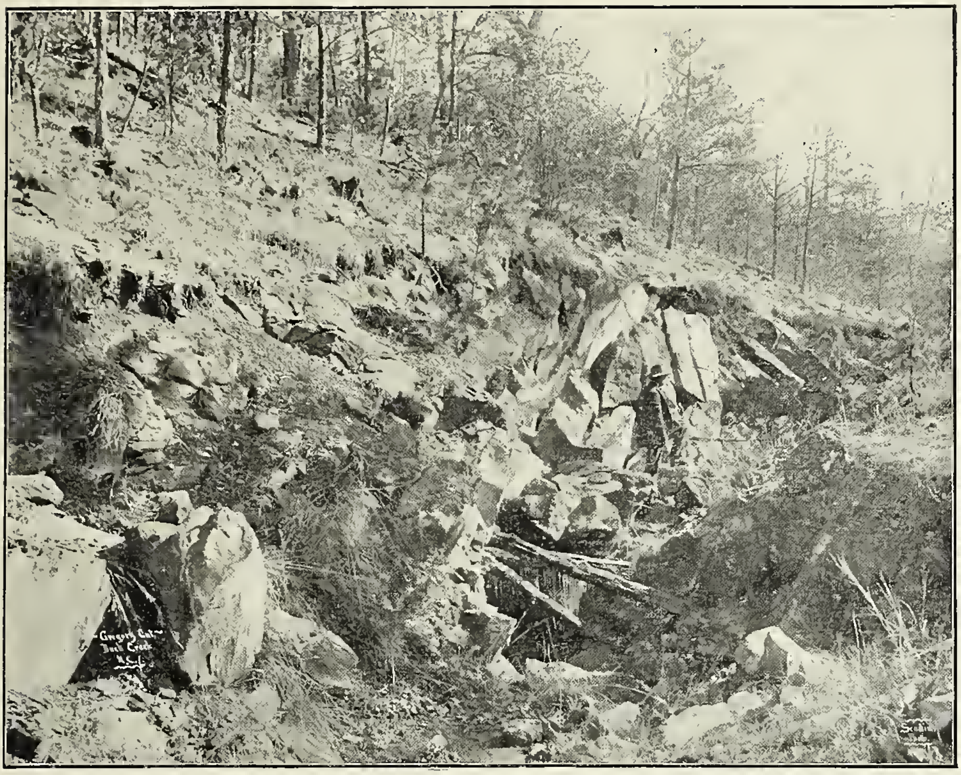
CORUNDUM IN IGNEOUS ROCKS.

CORUNDUM IN PERIDOTITE.

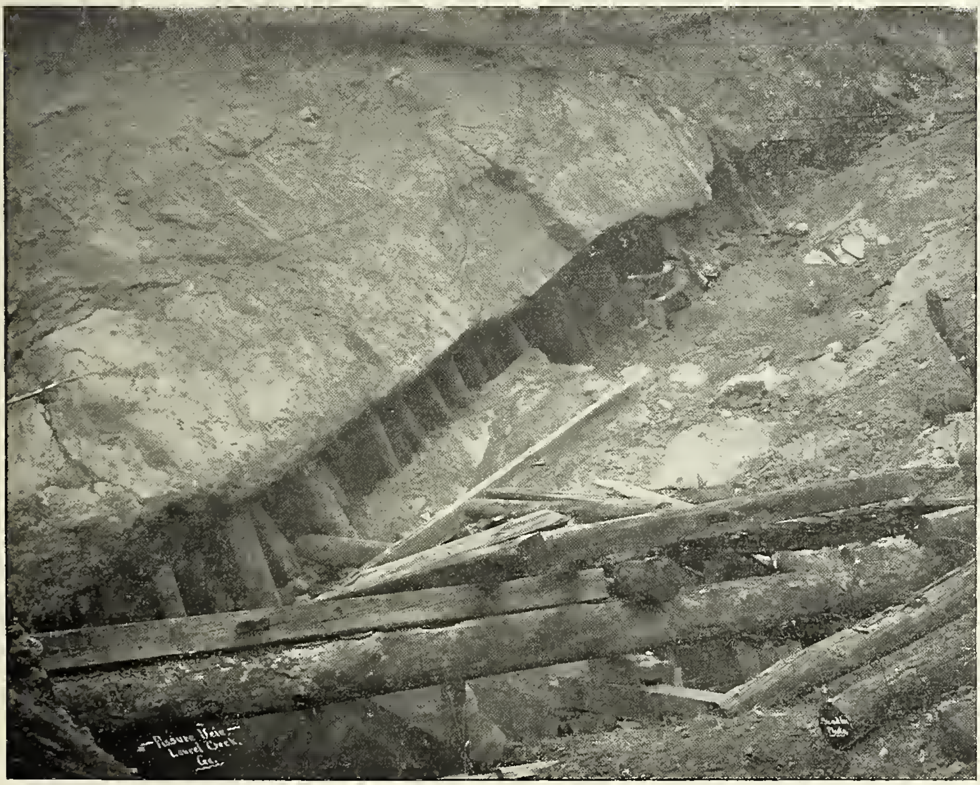
As described in Chapter I, the peridotites and associated basic rocks occur as oval, lenticular, and irregular masses and sheets in a region of metamorphic rocks composed chiefly of biotite-gneiss. As subordinate facies of this normal gneiss, however, more or less extensive areas of hornblende-gneiss, mica-schist, and quartz-schist are developed. Peridotites are found enclosed by or in contact with all of these various types. On account of greater resistance to weathering, as pointed out in Chapter I, it often happens that hornblende-gneiss is most conspicuous in outcrops, even where relatively unimportant in extent. Hence it has often been reported that the peridotites are always, or at least in most cases, associated with hornblende-gneiss.

The gneiss is usually considerably decomposed near the contact; and, while retaining the appearance of the unaltered rock, it readily crumbles when handled. The peridotite is also generally altered near the contact, but in a manner quite different from the gneiss. In fact it usually shows a strong tendency to completely decompose, so that only a residue of quartz or chalcedony and an ocherous, clay-like substance remains. This contact decomposition is altogether different from and independent of the alteration to serpentine, which almost universally characterizes the peridotites of this region. Only a moderate degree of serpentinization, however, is usually observed—not enough in the majority of cases to be visible to the naked eye—and in only a few localities has it proceeded to the extent of entirely replacing the original rock. For more detailed descriptions and studies of these alterations, see Chapter IV.

The corundum in these peridotites does not occur as an accessory mineral or rock-constituent, but is concentrated either near the contact of the peridotite and the enclosing gneissic rocks or in pockets within the mass of the peridotite. A series of secondary minerals, however, has been developed both along the contacts and with the corundum masses within the peridotite, so that the corundum is not usually found in direct contact with either the peridotite or the gneiss, nor are these rocks in contact with each other. The secondary minerals are chiefly chlorites, vermiculites, enstatite, and talc, and are not in any sense the results of contact metamorphism. It is customary to refer to these corundum-bearing zones as " veins," and that term is used here merely for convenience, without implying any particular character or origin. Those occurrences about the borders of the peridotites are designated as *peripheral* or *border veins,* and those wholly within the peridotite, as *interior veins.*



A, INTERIOR VEIN OF CORUNDUM IN PERIDOTITE AT BUCK CREEK, CLAY COUNTY, N. C.



B, INTERIOR VEIN OF CORUNDUM IN PERIDOTITE AT LAUREL CREEK, RABUN COUNTY, GA.

The veins of these two classes differ somewhat in appearance and general character. The interior veins trend approximately toward the center of the peridotite mass, generally growing gradually thinner in this direction until they pinch out altogether. This character was distinctly observed at Buck Creek, Clay County, North Carolina, and at Laurel Creek, Rabun County, Georgia (see Pl. XX, A and B). In the peripheral veins, however, the corundum seems to extend downward indefinitely along the plane of contact, varying irregularly, and sometimes very greatly both vertically and horizontally, but exhibiting no marked tendency to thin out in any particular direction. The peripheral veins often give off branches into the peridotite, which gradually thin out toward the center of the mass, and exhibit the usual characteristics of interior veins. These distinctions between the two types of veins have been observed by many of those who have mined and prospected for corundum in this region.

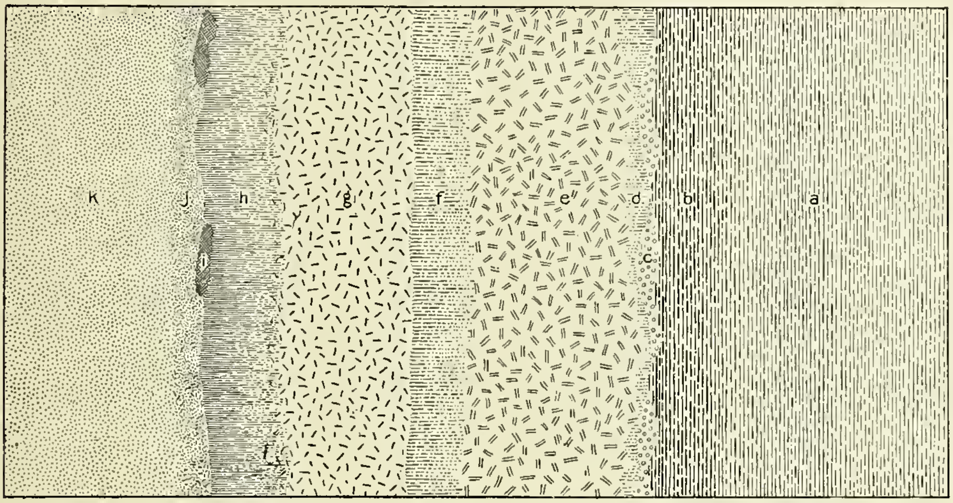


FIG. 19.—Ideal cross-section of a peripheral or border vein of corundum at the Corundum Hill mine, Macon County, N. C.

In a cross-section (fig. 19) of a peripheral or border vein the following is the usual sequence, from the gneiss to the peridotite:

a. Gneiss, hornblendic or micaceous, apparently unaltered.

b. Gneiss of same general appearance as *a,* but so decomposed that the particles readily separate from one another.

c. Yellowish vermiculites, varying considerably in thickness, with a maximum of 6 or 8 inches, often merging gradually into *d;* sometimes entirely absent, so that *b* and *d* are in contact.

d. Green chlorites, varying in thickness, much like *c,* and sometimes entirely absent.

e. Chlorites and corundum, often with some vermiculites, varying in thickness from a few inches to 12 or 15 feet. This is the "corundum-vein" of the miners, and in places consists largely of corundum.

f. Green chlorites, 1 inch to 12 inches in thickness; so far as observed, always present.

g. Enstatite, in places hard and compact, several feet thick, and usually merging into *h.*

h. Talcose rock, usually fibrous, and varying from a few inches to several feet in thickness.

i. A seam of yellowish clay a few inches in thickness, often carrying masses of quartz or chalcedony. This seam is frequently absent altogether.

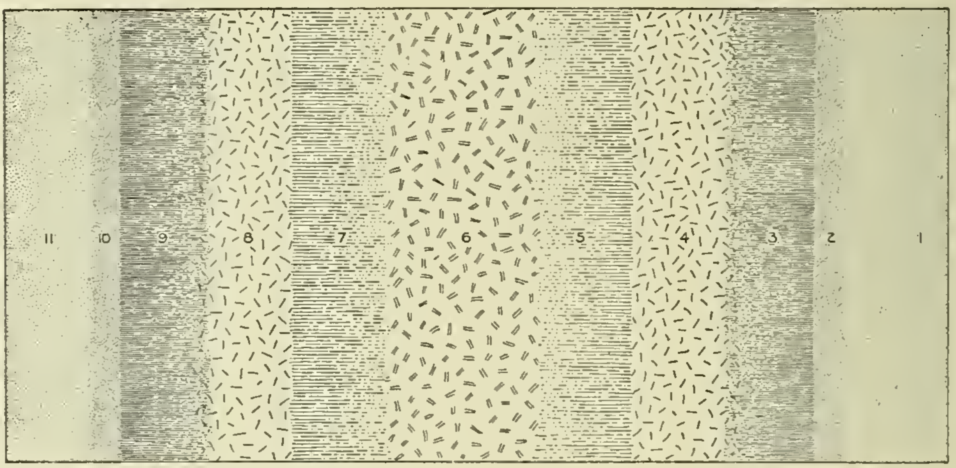


FIG. 20.—Ideal cross-section of an interior vein of corundum at the Corundum Hill mine, Macon County, N. C.

j. Dunite, more or less altered, friable and stained with ferric oxide.

k. Fresh dunite, usually exhibiting no alteration visible to the unaided eye. This constitutes the main mass of the peridotite.

As stated above, *c* and *d* are quite variable and sometimes absent altogether. When this is the case, *e.* the "corundum-vein," consisting of chlorites, vermiculites and corundum, is in direct contact with the gneiss *b.* The chlorite *f,* however, is always present on the peridotite side of the corundum-bearing zone. Not only are the separate zones above enumerated extremely variable in thickness, but the aggregate thickness of the vein is exceedingly inconstant, ranging from 3 or 4 feet to 30 or 40 feet in thickness sometimes in short distances. The accompanying diagram (fig. 19) represents the cross-section of a border vein observed at the Corundum Hill mine, Cullasaja, Macon County.

Photographs of mining on such veins at Corundum Hill are shown in Plates XXVI and XXVII.

In all of these peripheral or border veins the plane of contact between the hydrous secondary minerals and the gneiss is very sharp and distinct. The minerals developed between the corundum-bearing zone and the peridotite are invariably in greater abundance, and differ in character from those between this zone and the gneiss.

An interior vein was exposed in a shaft near the southern part of Corundum Hill for a distance of 20 to 25 feet, exhibiting the following cross-section, from either side toward the center (fig. 20):

1 and 11. Normal dunite.
2 and 10. Dunite, somewhat friable and discolored, passing into 3 and 9.
3 and 9. Fibrous talcose rock, merging into 4 and 8.
4 and 8. Grayish enstatite, somewhat fibrous.
5 and 7. Green chlorites, 6 to 15 inches in thickness.
6. Central corundum-bearing zone, consisting of chlorites, corundum, and spinel, 6 to 8 feet thick.

The symmetry of the vein is very marked, the different zones of minerals being encountered in the same order and in approximately the same thickness in approaching the central corundum-bearing zone from the dunite on either side. It will be observed that the succession of mineral on either side of the center is the same as on the peridotite side of the corundum-bearing zone in the border or peripheral veins. In these characteristics the cross-section given above is typical, being the same in all the interior veins examined.

Sometimes, instead of the talcose rock (3 and 9, in above cross-section), serpentine may be the limit of the vein next to the dunite. In one of the interior veins at Corundum Hill, near the west side of the outcrop, the corundum-bearing chlorite and vermiculite zone is in direct contact with serpentine on both sides. The zone is also divided and almost pinched out in one place by the serpentine.

An important variation from the normal modes of occurrence with peridotite, as just described, which has been observed at a number of localities, is the development of a zone of corundum-bearing plagioclase. This is found either in the corundum-bearing zone of chlorites and vermiculites (*e* and 6 of above cross-sections) or entirely replacing these zones. The feldspar, in the specimens determined, is a basic lime-soda species, is sometimes fine grained and compact, at others very coarsely crystallized, and varies, in different localities, from a few inches to several feet in thickness. In addition to the corundum it is found to contain, in different localities, large masses of zoisite, coarse black hornblende, and other minerals.

Examples of these feldspar veins are found at a number of places on Shooting and Buck creeks, in Clay County; at the Bad Creek mine, Sapphire, Transylvania County; and at the Carter mine, Madison County; also at the Track Rock and Laurel Creek mines, in Georgia. A similar interior vein at the Hamlin mine, on the headwaters of Ellijay Creek, in Macon County, contains a band of pegmatite, 4 inches thick, as its central member, and not bearing corundum, so far as observed.

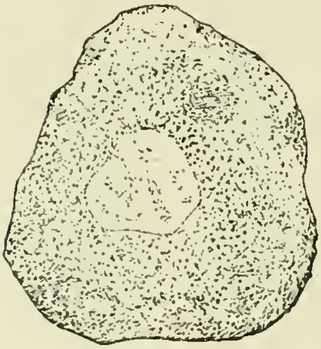


FIG. 21.—Corundum crystal surrounded by dunite; from the Hayes mine, Yancey County, N. C.

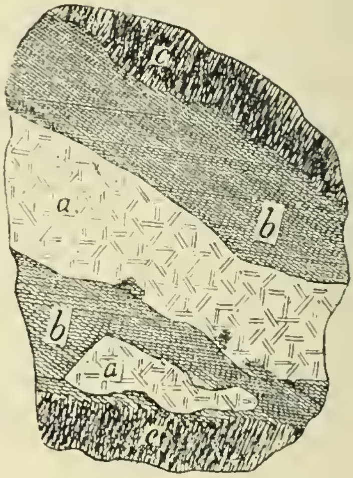


FIG. 22.—Corundum imbedded in serpentine; from Buck Creek, Clay County, N. C.

More complete lists and descriptions of minerals occurring in these various corundum-bearing zones will be found in Chapter IX.

Corundum inclosed immediately by peridotite, without intervening minerals, has been found at one locality; namely, the Hayes (Egypt) mine on the western slopes of Sampson Mountains, in Yancey County, Several specimens of this character were collected there by Mr. U. S. Hayes, who developed the corundum property in that section. Several irregular masses and one prismatic crystal were found inclosed in granular dunite (fig. 21); the latter is not quite fresh, but is stained yellowish brown by iron oxide and is somewhat friable. On the basal surfaces of the corundum a little muscovite is developed, as observed on corundum from other localities.

A careful search at all the corundum localities has failed to duplicate this occurrence in peridotite. Dr. C. D. Smith,[1] however, in describing

[1] Report of the North Carolina Geol. Survey, 1875, Appendix, p. 95.

the minerals associated with corundum at the Buck Creek locality, states that he found "chrysolite attached as an enveloping matter to considerable masses of corundum." But neither Dr. Smith nor any of the other writers who have described this locality since that time has made any further mention of this occurrence. A careful search has failed to discover any further specimens showing this association; and hence the occurrence at the Hayes mine is the only one known at the present time.

Corundum has been observed, however, in serpentine, which is one of the most common alteration products of the peridotites. Specimens of this nature have been found at the Cullakeenee mine, Buck Creek, Clay County. Some of them show small particles of corundum, either partially or wholly surrounded by serpentine, and the whole mass of corundum and serpentine surrounded by clinochlore. In one specimen a streak of corundum about an inch thick (*a*, fig. 22) lies between two zones of serpentine from one-fourth to three-fourths of an inch thick (*b*), and these are bordered, in turn, by a talcose material and enstatite (*c*), as represented in fig. 22.

Spinel has been found at a number of corundum veins, and at a few it is very intimately associated with the corundum. At the Carter mine, in Madison county (near Democrat, Buncombe County), the corundum occurs in pink and white masses intergrown with greenish black spinel. The masses of corundum and spinel are partially surrounded by a deep-green chlorite, which has also been developed in places between the corundum and spinel, though these two minerals are usually in immediate contact. A massive, coarsely to finely granular, greenish-black spinel has already been referred to as occurring in the interior veins at the Corundum Hill mine, in Macon County. Small grains and fragments of pink and white corundum occur disseminated through it.

Chromite, which always occurs in the peridotites of this region, is also found sparingly in many of the corundum veins. It is a well-observed fact that where there is any considerable quantity of corundum found in the peridotites there is a scarcity of chromite; and, conversely, that where much chromite occurs there is but little corundum.

An important variation from the usual mode of occurrence of corundum with peridotite, as in North Carolina, is found near Pelham, Massachusetts.[2] A lenticular mass of harzburgite (saxonite), about 40 feet in width of outcrop and about 200 feet long, is enclosed by gneisses. A zone of bronze-colored biotite usually 4 to 8 inches thick, but sometimes attaining a thickness of 4 feet, is developed along portions of the peridotite boundary. This biotite zone incloses hard nodules of blackish green hornblende and emerald-green actinolite, and other nodules consisting of large imperfect crystals of corundum, light gray in color, with spots and streaks of blue, wrapped in green chlorite. Still other nodules consist of friable masses of grass-green actinolite and of snow-white finely granular anorthite. The corundum occurs in comparatively small amount. Professor B. K. Emerson[3] states that "So much has been found . . . . that many bags have been sold for crushing."

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[2] Mon. U. S. Geol. Survey, Vol. XXIX, 1898, pp. 47-54.

CORUNDUM IN PYROXENITE.

At many of the corundum-bearing peridotite localities in Macon, Jackson, and Transylvania counties, a pyroxenite composed of interlocking coarse-bladed enstatite constitutes an important part of the outcrop; and at a number of places the pyroxenite alone forms oval and lenticular masses in every way similar to those composed of peridotite. In both cases, corundum-bearing zones of secondary minerals are frequently formed along the borders of the pyroxenite, intersecting the mass of the rock in exactly the same manner as described above for peridotites.

Corundum has also been observed sparingly in the pyroxenite itself in at least two localities; namely, at the Rattlesnake mine, near Sapphire, Jackson County, and at a locality on the West Fork of French Broad River, in Transylvania County.

Corundum is also intimately associated with a hypersthenite dike cutting the gneisses on Thumping Creek, Clay County, where it occurs in a zone of fine scaly brown mica developed along the plane of contact between the dike and the gneiss. It is also found in very small amount in the hypersthenite itself. The dike is a very dark, fine-grained rock, which the microscope shows to be composed of strongly pleochroic hypersthene about half altered to a green amphibole (see p. 72).

CORUNDUM IN AMPHIBOLITE.

Associated with the peridotites of portions of Clay County, North Carolina, and Towns County, Georgia, are numerous dikes of green amphibolite, varying from 25 to 300 feet in thickness. These usually occur along the contact of the peridotite and gneiss, or within the peridotite near the contact. The chief constituent of these dikes is a bright-green aluminous amphibole (edenite), which is often colored grass-green by the presence of small amounts of chromium. A more detailed description of these rocks is given on page 81.

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[3] Bull. U. S. Geol. Survey No. 26, 1895, p. 63.

The rock is usually very fine grained and exceedingly tough, and is often distinctly laminated. The corundum occurs as an accessory mineral in portions of the rock at several localities, varying from microscopic grains to masses several inches in diameter (fig. 23). Parting is usually well developed in the larger grains and masses parallel to the faces of the unit rhombohedron. The prevailing color of the corundum is deep pink, but it varies from almost white to dark ruby-red. On account of the contrast of these colors with the bright green of the amphibole, they often make handsome mineral specimens. Very rarely deep blue corundum has been found in these amphibolites. The exceeding toughness of the rocks, however, and the low percentage of corundum have thus far prevented them from being utilized as a commercial source of this mineral.

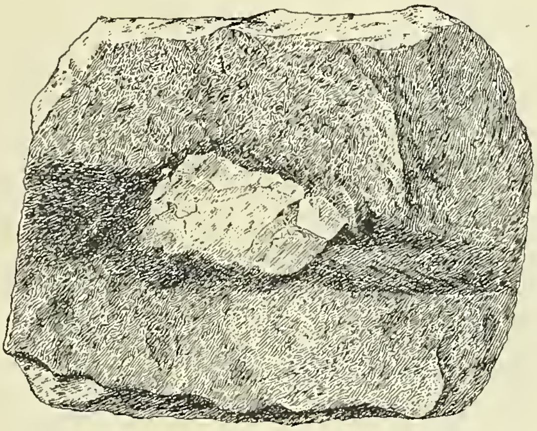

FIG. 23.—Corundum imbedded in amphibolite; Buck Creek, Clay County, N. C.

Four miles northeast of Canton, Haywood County, corundum occurs in small pegmatite dikes (Presley mine, p. 257) through a dark-green amphibolite. The rock is medium to fine grained and has brown mica disseminated through it in very small scales. In general character it is very similar to the amphibolites of Iredell County, described below.

At the Isbel mine, at the head of Shooting Creek, in Clay County, corundum occurs irregularly and sparingly disseminated through a decomposed hornblendic rock in small grains and masses. The least decayed portions of the rock seem to possess the characters of an amphibolite, but this could not be determined with certainty. The corundum occurs through the mass of this rock across an outcrop about 150 feet wide. In most of it the rhombohedral parting is distinctly developed. Possibly of a similar character are the emery deposits of Macon County (p. 251), and the corundum in hornblende-gneiss at Corundum Hill (p. 213).

Three miles east of Marshall and one-half mile northeast of the mouth of Ivy River, in Madison County, numerous crystals of corundum have been found over the surface of a large outcrop of coarsely crystallized dark-green amphibolite. In places the rock is of finer texture and contains some feldspar and biotite, passing into a dioritic facies. The country rock enclosing the amphibolite is a biotite-gneiss. Most of the corundum is in large, rough, hexagonal prisms. A crystal with three smaller prisms in twin position on alternate hexagonal edges was found which weighed 17 pounds (fig. 24. A and B).

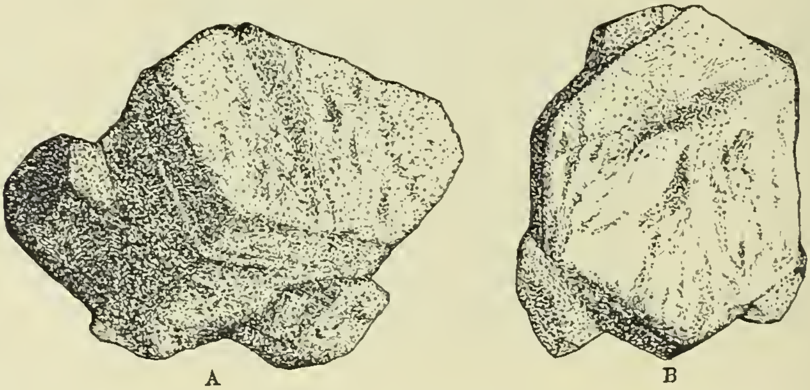

Fig. 24.—Twin crystal of corundum; from near Marshall, Madison County, N. C. (Two views of the same crystal.)

Doubtless many of the occurrences of corundum with chlorite-schists described below would be found to belong with the amphibolites if explored to greater depth, as at the Track Rock mine, in Union County, Georgia, where extensive outcrops of chlorite-schist have been found to consist chiefly of bright-green hornblende in the tunnel driven into the mountain side. Some portions of it also carry small quantities of olivine, possibly passing into amphibole-peridotite.

East of the Blue Ridge, in the western part of the Piedmont plateau, corundum is found in a dark-green amphibolite near Statesville, Iredell County. On account of the depth of soil and decomposed rock of this region, there are but few places where the fresh rocks are exposed, and but little is known of their extent. At Hunter's, 7 miles west of Statesville, however, open cuts in the bluffs of a small stream exposed the amphibolite in a comparatively fresh condition. The corundum occurs in fine brown vermiculites, with some chlorites, developed in zones from a few inches to 3 or 4 feet in thickness along the borders and penetrating into the amphibolite. A small feldspar vein, more or less kaolinized and sometimes bearing corundum, was encountered in some of these zones, though most of the corundum occurs in the vermiculites. The corundum occurs in irregular masses, crystals, and clusters of crystals, and is often accompanied and more or less surrounded by margarite, with smaller quantities of garnet and tourmaline. Occasional large masses of garnet were found inclosing crystals of corundum. Large boulders 2 to 4 feet in diameter, composed almost entirely of corundum and margarite, are found weathered out over the surface in this vicinity.

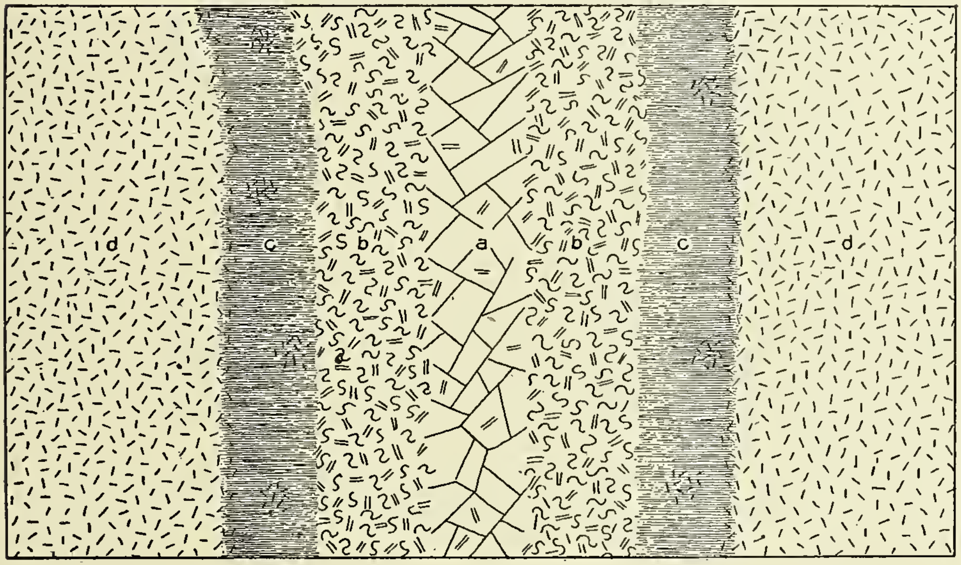

Fig. 25.—Ideal vertical cross-section of corundum in amphibolite at Hunters, Iredell County, N. C.

An entirely similar occurrence of corundum in scaly chlorites and vermiculites and feldspar veins through a much decomposed hornblende rock is reported by Mr. H. A. Collins (Statesville) to have been encountered under 18 feet of corundum-bearing alluvial deposits on a small stream 1½ miles west of Statesville. Work had been suspended at the time these deposits were visited, and only the alluvial sands and clays were visible. Materials found in the dump, however, were in every way similar to those in the workings at Hunters, described above.

Fig. 25 illustrates diagrammatically the mode of occurrence at these localities: *a* represents the feldspar vein that is sometimes encountered, more or less altered to kaolin and often bearing corundum; *b*, *b* are the vermiculite zones, carrying corundum in rounded masses, crystals, and clusters of crystals: *c, c* are radiating sheaths of actinolite, enclosing rounded masses of more or less decomposed amphibolite, *d*, often reduced to a mass of ocherous clay containing needles of hornblende and brown scales of vermiculite.

Dr. F. von Camerlander[4] describes the occurrence of corundum in the amphibolites of the northwestern part of Austrian Silesia. It is found in white or bluish grains and masses up to the size of a hazelnut. Corundum with hercynite also occurs in the amphibolites at Ronsberg, at the eastern foot of the Böhmerwald, in Bohemia.

CORUNDUM IN ANORTHOSITE.

As pointed out in Chapter II, page 31, the amphibolite, with its prevailing light-green amphibole and small amount of feldspar, that so frequently accompanies and intersects the peridotites of Clay County, N. C., and of Towns County, Ga., becomes in places highly feldspathic; and by the dwindling and disappearance of the amphibole, it passes into the anorthosite facies at several localities.

Anorthosites of this character, with more or less corundum in grains and irregular masses distributed through the rock, are found on the western slopes of the Chunky Gal Mountain and in association with some of the amphibolites of the Buck Creek area. These rocks are always greatly subordinate in amount to the associated amphibolites and peridotites, and never constitute more than an insignificant part of the outcrops.

An occurrence that may be contrasted in some respects with the above is found in South Sherbrooke, Lanark County, Ontario, Canada, in a rock composed largely of basic plagioclase and a little green hornblende, being somewhat more basic than the typical Canadian anorthosite. The corundum occurs sparingly in the rock in crystals of almost uniform size—about ½ inch in length. In color they are light gray to almost white, sometimes light pink.

Similar to this Canadian occurrence is the corundum-anorthite rock described by Dr. Jose J. Morozewicz[5] from a locality on the Barsowka River, in the Urals, Russia. The percentage of corundum in these rocks of the Urals seems to give promise of economic importance.

CORUNDUM IN PEGMATITE.

The occurrences of corundum in pegmatite are extremely rare, but it has been found in this rock in two localities in Haywood County, North

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[4] Verh. geol. Reichsanst., 1886, p. 356.

[5] Tschermak's Min. und Petr. Mitth., Bd. XVIII, Heft I.

Carolina. One of these is at Retreat, on Pigeon River, 6 miles southeast of Waynesville, where corundum occurs in small pegmatite dikes, cutting the saprolitic garnetiferous gneisses or schists. Accompanying these dikes are thin seams of vermiculites that also carry corundum (see p. 256).

The other locality is 4 miles northeast of Canton, at the Presley mine, where corundum occurs in a pegmatite dike which intersects a mass of dark-green amphibolite. The corundum is found surrounded by both feldspar and mica (see p. 257).

CORUNDUM IN METAMORPHIC ROCKS.

CORUNDUM IN SERPENTINE.

At a number of localities in North Carolina and Georgia, crystals and fragments of corundum surrounded by serpentine have been found in peridotites, the form of occurrence being similar to that described above from Buck Creek, Clay County. Nowhere, however, has corundum been found in the southern Appalachian region associated with the larger masses of serpentine that have been derived from the alteration of the peridotites, as in Buncombe County, described in Chapters II and III.

In Pennsylvania, however, in Chester and Delaware counties, corundum has been found in considerable quantities in massive serpentines, in relations practically identical with those seen at the occurrences of corundum with peridotites and pyroxenites in North Carolina and Georgia; and many of these Pennsylvania serpentines have undoubtedly been derived from original peridotites and pyroxenites.

CORUNDUM IN GNEISS.

Corundum has been found at a number of places in the ordinary gneisses of the crystalline belt in which the peridotites occur. As stated in Chapter I, "Geology of the Corundum Belt," the gneisses are extremely variable in character, passing frequently into mica-schist and at times into quartz-schist. Such transitions are sometimes very sudden, but usually there are thin zones of rock of intermediate character; and in some cases it is difficult, if not impossible, to decide just what should be called gneiss and what mica-schist. It can not, therefore, be claimed that the classification used here is in every case strictly accurate; and it may be that some occurrences here described as in mica-schist might have been placed by others under the head of gneiss, and *vice versa*. Some rocks that were at first thought to be gneisses are now regarded, perhaps more properly, as quartz-schists (see page 215).

In the eastern part of Clay County, on the southern slope of Gross Ridge, a spur of Chunky Gal Mountain, just above Thumping Creek, corundum has been found in the gneiss at a number of points. The rocks are so decomposed and so covered with soil that the exact relation of the corundum-bearing to the normal gneiss could not be definitely made out; but the former seems to occupy narrow zones in the latter. The gneiss is distinctly laminated and very fine grained, except the portions immediately surrounding the corundum, where its constituents are much more coarsely crystallized, especially the biotite. It is a hornblende-gneiss, showing but little mica except where it is associated with corundum.

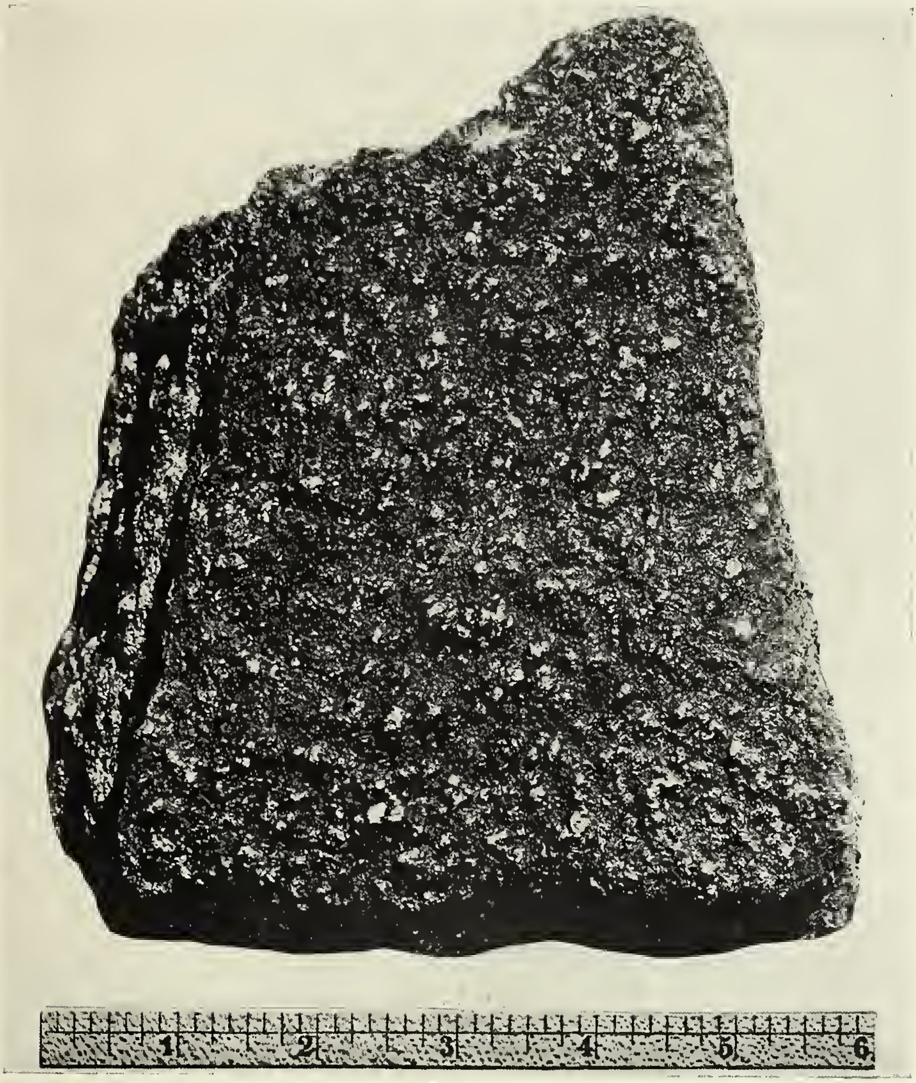
The corundum occurs in nodules and crystals half an inch or less in diameter, sometimes wrapped with muscovite, in a manner similar to that described in the discussion of its occurrence with chlorite-schists (p. 219). The crystals are prismatic, the length of the prism being usually twice or three times its diameter. Occasionally they are very flat, the prism then having a length of not over a quarter of an inch and a diameter of half an inch. From the appearance of these crystals this form of corundum is known locally as "button-corundum."

Near the head of Muskrat Fork of Shooting Creek, Clay County, the gneiss is cut by two parallel dikes of dark, fine-grained hypersthenite, about 10 feet thick and 500 to 600 feet apart, that extend about half way up the adjoining slope of Chunky Gal Mountain. The dike-rock consists of rounded, irregular grains of strongly pleochroic hypersthene, nearly half of which has been altered to a green amphibole (see p. 72). Corundum occurs in the gneiss between these dikes and in a band of black biotite intimately associated with a small vein of pegmatite, 2 feet thick. The biotite is developed in large scales and plates and carries nodules of corundum, some as much as half an inch in diameter, surrounded by scales of white mica (see A of Pl. XXI). Some of the corundum is also in the form of slender hexagonal crystals, known locally as "rat-tail corundum." This property was operated about twelve years ago as the Meminger and Hooker mine.

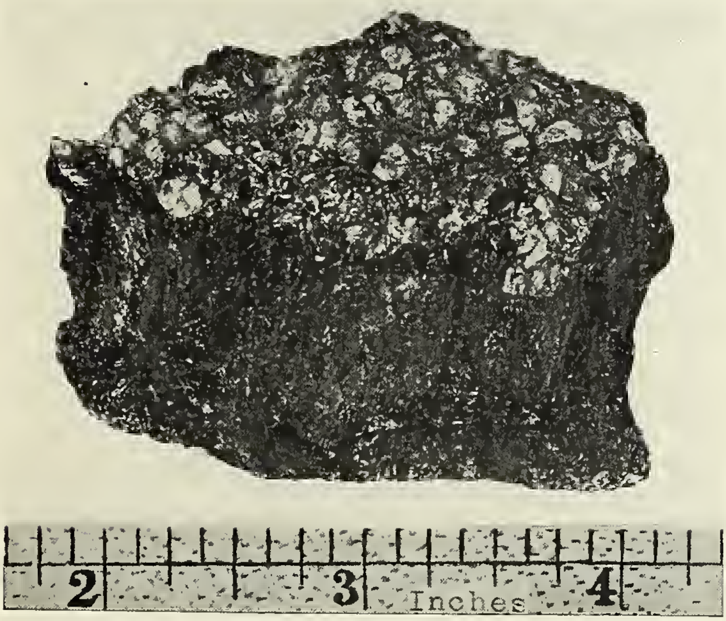
Corundum has also been observed in the hypersthenite of the lower dike close to its contact with the gneiss, and is developed in considerable abundance in a zone of fine, scaly, brown biotite formed along the plane of this contact.

Due north of this locality, on Muskrat Fork of Shooting Creek, corundum is found in the friable, decomposed gneisses, and prospecting has disclosed its presence over a considerable area.

Near the head of Muskrat Fork, on the western slope of Chunky Gal



A, CORUNDUM IN GNEISS, MEMINGER AND HOOKER MINE, CLAY COUNTY.



B, CORUNDUM IN CHLORITE, CORUNDUM HILL, MACON COUNTY, N. C.

Mountain, zones of brown biotite developed in the gneiss carry large nodules and irregular masses of garnet, which frequently contain corundum in small grains and thin tabular masses. The garnet also contains some spinel and frequently some pyrite.

At Corundum Hill mine, Macon County, one of the chief sources of corundum has been the peripheral or border vein developed along the southeastern border of the peridotite (see map, Pl. VI). When this mine was visited in 1895, the tunnel following this vein had encountered a tough, hornblendic rock in the gneisses adjoining the peridotite, varying in character from a hornblende-gneiss to a massive amphibolite and bearing corundum in considerable abundance, in grains and small crystals. At the time referred to this material was one of the principal sources of corundum, the rock being blasted out and hauled to the mills on wagons for crushing and cleaning. The exact nature of this rock is in doubt. The peridotite is everywhere bounded by biotite-gneiss and mica-schist, so far as appears at the surface; but as bands of hornblende-gneiss frequently appear in the biotite-gneiss, it might very well be a member of the gneisses proper. On the other hand, its occasional massive character, with its abundance of corundum, make it closely resemble the amphibolites that form dikes in and about so many of the peridotites in Clay County and the adjoining portions of Georgia.

On top of the mountain spur 2 miles north of the Corundum Hill mine, Macon County, there is an outcrop of enstatite-talc rock about 50 feet wide. The partially decomposed friable gneisses at the eastern border of this mass are corundum-bearing for a thickness of about 6 feet. The corundum occurs in small grains and is not abundant.

In Jackson County, just north of Betts Gap, in the Cowee Mountains, splendid grayish translucent crystals of corundum have been found in a garnetiferous gneiss. On Caney Fork of Tuckaseegee River, Jackson County, at the mouth of Chastains Creek, and also at a point 2 miles up Chastains Creek, corundum surrounded by muscovite is found in small grains and nodules, up to an inch in diameter, in biotite-gneiss. The nodules are often drawn out into small lenticular "eyes." The corundum is confined chiefly to the micaceous bands of the gneiss; and on account of the greater resistance of its muscovite coating, it stands out in prominent knots over the weathered surfaces of the gneiss. A similar occurrence is found in the gneiss at the mouth of the North Fork of Ellijay Creek, in Macon County. Three miles north of this locality, on the summit of Turkey Knob, corundum is found in a decomposed hornblende-gneiss.

Six miles southeast of Burnsville, Yancey County, on Celo ridge, near

South Toe River, corundum is found in almost the same relations as those found on the mountain north of Corundum Hill mine, described above. Here there is an outcrop of enstatite rock, about 50 feet wide, partly altered to talc, along the eastern border of which some chlorite is developed, and in the adjacent decomposed gneisses corundum is found for a distance of 2 or 3 feet from the contact. The corundum is in irregular masses and imperfect crystals up to 2 or 3 inches long, and is often more or less enclosed in radiating muscovite.

Corundum occurs in decomposed gneiss associated with no other recognizable rock, three-fourths of a mile northwest of Bakersville, Mitchell County, on the Johnson City road. So far as could be ascertained, the conditions here are very similar to some of those on Shooting Creek, in Clay County, described above.

Six miles southwest of Franklin, Macon County, a number of crystals and irregular masses of corundum have been found in the fields about Nonah Post-office. The rock seems to be only decomposed gneiss, and this is doubtless the source of the corundum.

Near the confluence of Owens and Parker creeks, which form the West Fork of French Broad River in Transylvania County, several large boulders of light green cyanite have been found on the surface, bearing grains and small crystals of a deep sapphire-blue corundum. The rocks of the vicinity are gneisses, and these are undoubtedly the source of these cyanite-corundum aggregates.

Several other scattered occurrences of corundum that have furnished occasional specimens may, with a reasonable degree of assurance, be assigned to the gneisses, or possibly, in some instances, to mica-schists. These localities, so far as noted, are as follows: corundum with cyanite on Coweta Creek, Macon County; with cyanite on Crowder, Chubb, and Kings mountains, Gaston County; several localities in Iredell County, in some cases associated with cyanite.

CORUNDUM IN MICA-SCHIST.

Just south of the divide in the Cowee Mountains, in the gap at the head of Ellijay Creek, Macon County, is the Haskett "mine," where corundum is found in a decomposed, friable garnetiferous mica-schist. The corundum is buish gray and occurs in grains and small nodules. The schist sometimes carries scales of graphite, and in places is quite gneissic in character. Limestones occur within half a mile southwest of this locality, and at intervals for 2 miles in the same direction.

Two miles southwest of Balsam Gap, in Jackson County, masses of cyanite with some corundum are found in the mica-schist in a railroad cut a few hundred feet east of the large peridotite mass. The schist is sometimes garnetiferous, sometimes shows also small amounts of scaly graphite, and in some portions a gneissoid character is developed. Similar masses of corundum-bearing cyanite have also been found on the surface in the vicinity.

An occurrence in many ways similar to the last is found at Retreat, 6 miles southeast of Waynesville. on the West Fork of Pigeon River, in Haywood County. Corundum with and without associated cyanite, in irregular masses and barrel-shaped crystals, is found over the surface. The rocks are garnetiferous mica-schist with gneissic facies, as at Balsam Gap, and are intersected in places by small pegmatite dikes. Much of the corundum is wrapped in a thin coating of a very compact material resembling damourite.

Tapering prismatic crystals of grayish blue corundum are found on the surface on the ridge leading northwest from Carpenters Knob, along the borders of Burke and Cleveland counties, near the corner of Catawba, in a region of garnetiferous mica-schist.

It is quite possible that some of the corundum-schists of South Africa, described below under the head of "Modes of Occurrence not found in America," may be highly corundiferous facies of mica-schists or quartz-schists, and hence comparable to some of the North Carolina localities described above.

For comparison also may be mentioned an occurrence described by Dr. Genth[6] from a locality 2 miles from Stuart, in Patrick County, Virginia. Here mica-schists, sometimes garnetiferous and gneissic, are intersected by granite dikes, and corundum is found over the surface, associated with andalusite, cyanite, chloritoid, and mica. The corundum varies greatly in color, occurs in tapering hexagonal crystals and irregular masses, and sometimes only in microscopic grains enclosed in the mass of associated minerals.

It is quite possible that some of the localities where surface specimens of corundum have been found with cyanite, as described above under "Corundum in Gneiss," may belong here. Where only surface fragments have been found, assignment to their original rocks must, of course, be only tentative until the mineral is found in place.

CORUNDUM IN QUARTZ-SCHIST.

In the eastern part of the Shooting Creek Mountains, near the State line between Clay County, North Carolina, and Towns County, Georgia, numerous zones or bands of crystalline rocks have been found to be corundum-bearing. The rocks vary from normal gneiss to a non-feldspathic type which is best described as a quartz-schist, composed of quartz with biotite-mica. Some portions are rich in garnet, and there are small bands of white quartzite. They are distinctly laminated, and are frequently intersected by granitic dikes, some of which are coarsely crystallized and of a pegmatitic character. These dikes are often parallel with the lamination of the schists, though many of them cut irregularly across it. When the dikes are parallel to the lamination, the structure is more apparent. The general strike of the lamination is northeast-southwest, and the dip is to the northwest, at an angle of about 30°.

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[6] Am. Jour. Sci., 3d ser., Vol. XXXIX, 1890, pp. 47, 48.

Portions or bands of these schists are corundum-bearing, but they are irregularly defined and gradually merge into the normal rock. Their relations to the normal schists are similar to those that the garnet-bearing bands bear to the normal gneiss in which they occur. These bands vary in thickness from 1 foot to 12 or 15 feet; but in the thicker ones the corundum-bearing portion is interlaminated with zones of barren rock and granitic dikes.

These corundum-bearing bands form at least two parallel belts about 2 miles apart, and can be traced for a distance of 5 or 6 miles in a northeast-southwest direction, sometimes outcropping continuously for nearly a mile. The two belts differ somewhat in the proportions of corundum and garnet; otherwise they are identical. The percentage of corundum is never high; and from determinations made on samples from various parts of the region, it was found to vary from 2 to 5 per cent.

The corundum occurs, for the most part, in small particles and fragments that have no definite shape, and are of a gray, white, and bluish white color to almost colorless. It also occurs in crsytals that are usually fairly well developed in the prism zone, and vary in size from very minute to a length of 2½ inches and a diameter of about one-half inch. Suggestions regarding the origin of the corundum in these schists are given on page 356, Chapter X.

CORUNDUM IN AMPHIBOLE-SCHIST.

At the Sheffield mine, in Cowee Township, Macon County, corundum has been mined in a saprolitic (or decomposed) rock at various times for a number of years. In sinking a shaft 8 feet square to penetrate the depth of the corundum-bearing saprolite, the solid unaltered rock was encountered. The shaft was 87 feet deep and showed the following sequence downward (fig. 26): the first 12 feet (*a*) was through saprolite, in which there were seams of kaolin; the next 2 feet (*b*) were corundum-bearing. From 14 to 28 feet (*c*) the same saprolite was encountered, then another 2 feet (*d*) that was corundum-bearing, followed by another 10 feet (*e*), that is, from 30 to 40 feet, of saprolite and two feet more (*f*) that were corundum-bearing. From 42 to 63 feet (*g*) the rock began to be less decomposed; and from 63 to 66 feet (*h*) another seam of corundum-bearing rock was encountered. From this point to the bottom of the shaft the rock became more and more solid until, at 77 feet, the fresh rock was encountered. These various seams in the rock are very pronounced, and dip 30° toward the west near the top, becoming nearly horizontal nearer the bottom of the shaft. The seams of decomposed feldspar observed in (*a*) become less and less kaolinized until in (*i*) they consist of pure plagioclase feldspar. In (*i*) there are two seams of corundum similar to (*b*), (*d*), and (*f*), although in the fresh rock these seams are not so pronounced as in the saprolitic rock. There is often considerable feldspar bordering the corundum-bearing seams. The general trend of the rock is about N. 5° to 10° E. The vertical section of this shaft, as described above, is represented in fig. 26.

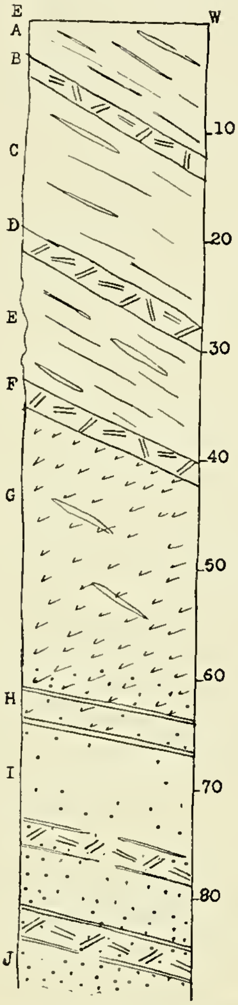

FIG. 26.—Vertical cross-section of shaft at Sheffield mine, Macon County, N. C.

It is seen that in both the solid and saprolitic rocks the corundum occupies seams a few feet thick at irregular intervals; and, while the corundum may constitute 10 per cent or more of these seams, its percentage of the total amount of rock that must be moved in mining would probably always be small. The actual width of outcrop of this rock is not known, but the saprolitic surface material has been cut across for nearly 100 feet in a direction about at right angles to the strike.

The fresh rock at the bottom of the shaft is somewhat varied in appearance; and, while it does not all show definite gneissoid structure, the more finely divided portions are distinctly laminated. There are streaks a few inches thick composed almost wholly of a plagioclase feldspar. Some portions of the rock are decidedly porphyritic and contain phenocrysts of a light gray amphibole, a centimeter in diameter, in a groundmass of feldspar. A large part of it, however, is made up of small, roughly outlined prismatic crystals of amphibole, probably hornblende, and irregular fragments of plagioclase feldspar. The amphibole is almost black in color, but in thin splinters it has a bronze luster and a resin-brown color. Biotite of a deep-brown color also occurs sparingly, and a pink garnet is rather abundant. This part of the rock is of a gneissoid structure and in this corundum occurs. The corundum is light pink to purplish in color and forms nodules up to two or three centimeters in diameter. Some streaks in the rock are highly garnetiferous, composed essentially of garnet and plagioclase feldspar, or of garnet and biotite. Chalcopyrite occurs very sparingly in these portions of the rock. Small particles of graphite have been observed in the coarsely crystallized portions.

Professor L. V. Pirsson, of Yale University, has kindly made a microscopic examination of this rock, the results of which are embodied in the following paragraphs.

In thin section the microscope disclosed the minerals: hornblende, plagioclase feldspar, garnet, biotite, muscovite, staurolite, and rutile. Hornblende is the most common, forming about two-fifths of the section, while of the remainder plagioclase and garnet constitute about equal proportions, with the others in comparatively insignificant amount.

The hornblende is formless, but tends to irregular columns almost invariably extended in the plane of schistosity. It has very rarely a somewhat stringy tendency in its cleavage, but is usually homogeneous in broad plates. Its color is a clear olive-brown, and it is somewhat pleochroic but not strongly so. It is everywhere dotted by the small grains of garnet, which rarely show good crystal form. The garnet occurs associated also with the plagioclase.

The plagioclase occurs twinned according to the albite law only. In sections perpendicular to 010, the lamellæ show extinctions as great as 30°, and the plagioclase is therefore rich in lime and as basic as labradorite, which it probably is. It shows strong evidence of shearing movement in the rock; it is often broken, exhibits rolling extinctions, and the albite lamellæ are curved and bent. It runs along the planes of schistosity between the amphiboles and forms a mosaic of angular broken grains.

Staurolite was found in rather broad, irregular grains, and rutile in small irregular grains and well-crystallized prisms.

Professor Pirsson has indicated that the character and structure of this rock, composed chiefly of amphibole, labradorite, and garnet, suggests most strongly that it is a metamorphosed igneous rock of the gabbroid family. During the metamorphism the augite of the gabbro would be converted into the brown hornblende. Any iron ore that was present would be taken up by the hornblende and garnet. The rutile would have resulted from the titanic acid that is a regular component of the iron ores in the gabbros and diabases. Staurolite is a widespread product of metamorphism in the schistose rocks, and is naturally expected. The feldspar has suffered least chemically, except the corundum, and shows only the shearing of dynamic processes.

The corundum does not occur in crystals, but in small fragments and in elongated nodules, which are cracked and seamed, and appear to have been drawn out by the shearing processes. The general character and shape of the corundum would indicate that it was an original constituent of the igneous rock, and not formed during its metamorphism.

As the exact nature of the original rock is not apparent, it is here called simply an amphibole-schist, in accordance with its present character.

CORUNDUM IN CHLORITE-SCHIST.

Besides the occurrence of corundum in the more or less schistose chlorites (B of Pl. XXI) in peridotites and pyroxenites, as described above, it has been found in the long belts of chlorite-schist that traverse the country 10 to 12 miles southeast of Webster, in Jackson County. These rocks sometimes attain a thickness of several hundred feet, and are traceable across the country for several miles. They are composed almost entirely of green, scaly chlorite, though sometimes small feldspar grains and occasional amphibole needles are present. The chlorite is in small scales, never very coarse, as is sometimes the case in the zones about the peridotites, and often they are so minute as to give the rock a very compact appearance.

On the south side of Caney Fork of Tuckaseegee River, 2 miles above its mouth and one-fourth of a mile above the mouth of Moses Creek, a corundum-bearing zone of chlorite-schist is exposed in a small prospect pit. For a thickness of 8 feet the schist is thickly studded with nodules of corundum, varying chiefly between one-fourth and one-half inch in diameter, but sometimes larger. The corundum is wrapped in a white coating of mica, which is often arranged in radiating scales perpendicular to the outer surface of the corundum. These coatings are extremly variable in thickness, sometimes being very thin, sometimes developed to great thickness, with perhaps only a small grain of corundum at the center.

Surface specimens of corundum have been found over the outcrop of chlorite-schist at numerous places further up Caney Fork, and also at localities along the main stream to the south.

Just across the State line to the southwest, in Towns and Union counties, Georgia, numerous outcrops of chlorite-schist occur on the waters of Brasstown and Arququa creeks, many of them corundum-bearing. In some cases these schists are associated with outcrops of recognizable peridotite or troctolite, but in the majority of cases only the chlorite-schist is visible. To all appearances these outcrops are similar in character to those just described in Jackson County, North Carolina. In one of these localities, however, at the Track Rock Gap corundum mine, it has been shown that the chlorite-schist is an alteration product of amphibolite or an amphibole-peridotite,[7] specimens only partially altered being brought to light in the deeper workings.

CORUNDUM IN ALLUVIAL DEPOSITS.

CORUNDUM IN GRAVEL DEPOSITS.

The gem varieties of corundum are found chiefly in the soil and gravel beds, as those of Burma, Ceylon, and other regions of southern Asia, and the sapphire deposits of Montana. Together with these are also found the commoner varieties of crystallized corundum; and in some of the localities the mineral has been traced to its origin in the crystalline rocks.

The gravel beds represent the result of ages of concentration, during which the rocks have been slowly decomposing and crumbling away through the agencies of air and water. The stream beds furnished a natural system of sluices in which the heavy and more resistant minerals have been caught and retained, while the lighter materials have been carried further down the valley. Thus, if all the material transported by a stream had been of about the same degree of fineness, there would have been an almost perfect deposition of the different minerals according to their specific gravity, the heavier ones being deposited higher up the stream and nearer their place of origin. Again, if the materials transported had been of various degrees of coarseness but about the same specific gravity, there would have also been an almost perfect sorting of the materials according to sizes, the coarsest farthest up the stream. As both of these processes of deposition are going on at the same time, we find the heavy minerals and the large bowlders and fragments of the lighter ones intermingled and thus forming the alluvial gravel deposits as they are seen at the present time (see Pl. XVII, A).

Although corundum gems may have been very rare in the original rock, they have been concentrated in these gravel deposits, and are thus found in comparative abundance. Even when the corundum of the

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[7] F. P. King, Bull. Geol. Surv. Georgia No. 2, 1894, pp. 92-95.

TESTING GRAVEL DEPOSITS FOR CORUNDUM, MACON COUNTY, N. C.

gravel deposits is traced to its original source in the rocks, the gravels often still remain the principal commercial source of the gems.

Many of the corundum deposits of North Carolina have been found through the discovery of fragments in the soil or in the beds of the streams; and prospectors wash the gravels of stream beds for corundum, in much the same way that search is made for gold (Pl. XXII). Similarly, corundum crystals have been plowed up in bottom lands, and further investigations have revealed gravel beds, often of considerable extent, which usually bear several varieties of corundum. By searching up the stream and its tributaries until no further trace of corundum can be found, and then up the adjoining hillsides, the original source of the gravel deposits in the valleys has often been revealed. But in a number of cases such search has, thus far, proved fruitless; and we are led to the conclusion that the corundum has been concentrated from rocks in which it is only a rare constituent.

UNDETERMINED OCCURRENCES OF CORUNDUM.

In 1852 Dr. C. L. Hunter[8] observed masses of emery associated with crystalline corundum in granular quartz-mica aggregates at Crowders Mountain, in Gaston County. Dr. F. A. Genth[9] has also described emery associated with titaniferous iron ores near Friendship, in Guilford County. It has also been found on Mine Fork of Jacks Creek, 3 miles north of Burnsville, in Yancey County, associated with staurolite; and extensive emery deposits, 5 to 7 miles southeast of Franklin, Macon County, have been described by Dr. Joseph Hyde Pratt[10] as occurring in thoroughly decomposed rock (p. 251).

OTHER OCCURRENCES OF CORUNDUM IN AMERICA.

Besides the modes of occurrence in North Carolina, as described above, corundum is known to occur in other parts of America in the following rocks:

Corundum-bearing rocks in America not found in North Carolina.

IGNEOUS.

Granite.
Syenite.
Nepheline-syenite.
Plumasite.

Norite.
Andesite.
Monchiquite.

METAMORPHIC.

Crystalline limestone.

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[8] Am. Jour. Sci., 2d ser., Vol. XV, 1853, pp. 373-378.

[9] Report Geol. Survey North Carolina, 1875, p. 246.

[10] Bull. U. S. Geol. Survey No. 180. 1901, p. 72.

Some examples of these modes of occurrence are briefly described below, but no attempt has been made to give a complete list of localities.

CORUNDUM IN GRANITE.

At Nannies Mountain, 12 miles northeast of Yorkville, South Carolina, corundum occurs in considerable quantities in a light gray biotite-granite. It forms irregular masses of a black color, varying from small grains to several inches in thickness, and usually has a well-developed parting. It is invariably imbedded in muscovite, which varies from fine scaly aggregates to compact, massive damourite. At the Rickard mine, at the north end of the mountain, a shaft 35 feet deep has been sunk and several drifts have been made from this; but, as operations have been suspended, these workings cannot be examined. Hence, the exact relations of the corundum masses to the granite cannot be made out. Only granite, however, in various stages of disintegration, and masses of corundum and muscovite were taken from these workings.

Dr. A. Lacroix[11] found corundum in masses of granite included in the volcanic rocks of Auvergne, France; and its occurrence as an occasional accessory in normal granites is mentioned in the petrographical works of both Zirkel and Rosenbusch.

CORUNDUM IN SYENITE.

A deposit of corundum in syenite is located in the south-central part of Gallatin County, Mont., on the headwaters of Elk Creek, in a group of foot-hills between the Gallatin Valley and Spanish Creek basin. It is about 23 miles south of Belgrade, Gallatin County, which is on the Northern Pacific Railroad. The corundum has been found in a rock that is composed essentially of orthoclase feldspar, corundum, and biotite, with the feldspar predominating. The rock for the most part has a somewhat gneissoid structure, and in these portions the corundum is more or less finely divided, being in fine grains and small crystals. In other portions, where the corundum is coarsely crystallized, the rock has something of a pegmatitic character, and the corundum is surrounded by the orthoclase. While this has been called a corundum-bearing biotite-syenite,[12] yet from the number of occurrences that are being recorded of this mineral acting as a component of these rocks, as those in Canada and in the Urals, it would seem desirable to recognize rocks of this type as corundum syenites.

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[11] Bull. des Serv. de la Carte geol. de France, Vol. II, No. 11. See Bibliography.

[12] U. S. Geol. Survey, Bull. 180, 1901, p. 31.

According to Mr. L. S. Ropes, manager of the Montana Corundum Company, which is operating these deposits, the crystals of corundum vary from a fraction of an inch up to 8 inches in length, some having been found that weighed 1½ to 2 pounds. In the pay streak or band of this corundum-bearing syenite, which is from 28 to 34 inches in width, the percentage varies from 10 to 70 per cent. The full width of the corundum-bearing syenite, as determined by Mr. Ropes, is from 8 to 10 feet.

Somewhat similar to this is the occurrence of corundum in dikes of syenite which penetrate the gneisses over extensive areas of Haliburton, Peterborough, Hastings, and Renfrew counties, Ontario, Canada. The corundum occurs in white or gray to bronzy crystals in the rock, varying from half an inch to 2 or 3 inches in diameter, and from one to 4 or 5 inches in length. It is extremely variable in amount, ranging from less than 10 per cent to 30 or 40 per cent of the rock mass. An average of 12 to 15 per cent has been reported from some localities. Besides corundum, the syenites carry small amounts of magnetite, pyrite, garnet, zircon, and sodalite.

CORUNDUM IN NEPHELINE-SYENITE.

The syenites found in the Province of Ontario, Canada, and referred to above, are partly mica, hornblende, and nepheline-syenite. The mica and nepheline-syenites are often closely associated and are corundiferous. In some of the nepheline-syenites a nearly transparent bluish corundum of gem quality has been found.

CORUNDUM IN PLUMASITE.

Prof. Andrew C. Lawson has recently described an interesting occurrence of corundum from the eastern slope of Spanish Peak, Plumas County, Cal., about 2 miles east of the summit. An oligoclase-corundum rock occurs here, which Professor Lawson has called plumasite, and which he describes as a dike cutting a large area of amphibole-peridotite. He does not give the location of this rock, however, with reference to the contact between the peridotite and the Carboniferous rocks into which it has been intruded.

The maximum width of the dike, as observed, is about 15 feet, and it could be traced for a distance of only 125 feet. At one exposure it consists of a coarse allotriomorphic granular aggregate of white feldspar, in which are embedded crystals of corundum up to 2 inches in length and 1 inch in diameter. The corundum is of pale violet-blue color and constitutes about 16 per cent of the rock. At the only other two places where this rock outcrops Professor Lawson was unable to discover any corundum.

CORUNDUM IN NORITE.

In the vicinity of Peekskill, Westchester County, New York, the occurrence of corundum in norites, associated with a series of peridotites and diorites, has been described by Dr. G. H. Williams.[13] This group of eruptives has been termed the "Cortlandt series," and the prevailing rock-type is characterized by the presence of the mineral hypersthene. Typical norite, however, consisting of only plagioclase feldspar and hypersthene, is extremely rare.

Magnetite and emery have been found in portions of these norites in the vicinity of Crugers. Corundum is scattered rather sparingly through the emery, which contains a great deal of the iron-magnesium spinel, pleonaste. The corundum varies from minute colorless grains to some that are as large as 7 mm. in diameter and hexagonal in outline. Occasionally even larger specimens of a blue color are found. The emery is mined to a limited extent, but, owing to the predominance of spinel over corundum (it is, in fact, a spinel-emery) it is softer than true emery.

Fragments of mica-schist included in the eruptive are altered into a great variety of metamorphic minerals, arranged in more or less distinct zones. Beginning at the surface, these consist of corundum and pleonaste followed by quarts with magnetite, pleonaste, zircon, apatite, sphene, garnet, tourmaline, and many others.

Very similar to the spinel-emery of the Cortlandt norites are the occurrence of granular corundum and spinel in the basic aggregates in gabbros at Frankenstein and Veltlin, Germany, referred to on page 228.

CORUNDUM IN ANDESITE.

An interesting occurrence of sapphire corundum is found in a dike of andesite that is exposed at French Bar, on the Missouri River, 12 miles northeast of Helena, Montana. The dike is 3 to 6 feet thick and cuts through slates. The rock is fine grained and rather light gray in color, and the groundmass is a brown glass speckled with microlites of a lath-shaped plagioclase feldspar. Imbedded in this groundmass are thickly scattered plates of biotite, and, more sparingly, crystals of augite. Corundum crystals, yellowish green in color and of gem quality, occur very sparingly in the rock.

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[13] Am. Jour. Sci., 3d ser., Vol. XXXI, 1886, 26-41; Vol. XXXIII, 1887, 135-144, 191-199; Vol. XXXV, 1888, 438-448; Vol. XXXVI, 1888, 254-269.

Corundum in andesite has also been described from several European localities. Dr. A. Osann[14] found corundum associated with spinel, biotite, sillimanite, andalusite, rutile, zircon, etc., in a mica-pyroxene-andesite in the vicinity of Cape de Gata, in southeastern Spain. The corundum forms flat basal plates with striations parallel to the rhombohedron. The rock also contains numerous dark micaceous inclusions.

Dr. A. Lacroix[15] describes the occurrence of corundum in the trachytes, andesites, and basalts of the volcanic district of the Auvergne Mountains, in the central plateau of France. The corundum is associated with zircon, diaspore, sillimanite, etc. The rocks also contain numerous acid inclusions that have been more or less completely destroyed by fusion or solution in the enclosing magma. When not completely destroyed, the inclusions also frequently contain corundum associated with numerous metamorphic minerals.

The trachytes, andesites, and basalts of the Siebengebirge, in Germany, as described by Dr. A. Dannenberg,[16] also contain corundum, spinel, magnetite, sillimanite, and numerous inclusions of sandstone, schist, and granulite.

A hornblende-andesite of the Eifel, Germany, described by Dr. F. Vogelsang,[17] contains numerous granular aggregates of cordierite, andalusite, sillimanite, feldspar, biotite, corundum, spinel, rutile, quartz, zircon, and magnetite, without recognizable inclusions of rocks.

CORUNDUM IN MONCHIQUITE.

Near the entrance to Yogo Gulch, Fergus County, Montana, sapphire corundum has been found in an igneous rock that is exposed in two parallel dikes 600 feet apart, which cut through the sedimentary rocks. Although these dikes are almost identical in appearance and composition, only one of them contains corundum.

The dike rock has a dark gray basic appearance, and is very tough, breaking with uneven fracture. It is composed for the most part of biotite and pyroxene closely crowded together. The small interstices between them are filled with a brownish kaolin-like aggregate, which apparently represents some former feldspathoid constituent. In regard to the classification of this rock, Professor Pirsson[18] says:

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[14] Zeits. der deutschen geol. Ges., Vol. XLI, 1889, 297; Vol. XLIII, 1891, 688.

[15] Bull. Soc. Min. Fr., Vol. XIII, 1890, 100-106, etc. See Bibliography.

[16] Min. und Petr. Mitth., Vol. XIV, 1894, 17.

[17] Zeits. der deutschen geol. Gesells., Vol. XLII, 1890, 1; Am. Nat., 1892, pp. 165-166 (abst.).

> In thin section the rock at once shows its character as a dark basic lamprophyre, consisting mainly of biotite and pyroxene. . . . . The rock appears to have its closest affinities in the monchiquite group, of which it may be considered a basic, somewhat altered type. The abundance of biotite shows its relation to the minettes, but the rock is much richer in the ferromagnesian components and lacks the feldspar of the minettes. It has evidently a close affinity with the minettes and shonkinite of the region, and is clearly a more basic form of the same magma. It has the same richness in biotite and pyroxene as these, but differs in the feldspathic component.
>
> Following Rosenbusch's classification, it may be said that this rock seems to be a basic member of the monchiquite-camptonite series of lamprophyres, the rocks at one end of which are characterized by an abundance of biotite and augite or hornblende. The rock is too rich in ferromagnesian and too poor in feldspathic constituents to be called a minette or kersantite, and the total absence of the feldspar and the small quantity of feldspathoid make it a very basic member of the general monchiquite group of Rosenbusch.
>
> The sapphire corundum occurs rather sparingly in this rock in well formed, flat, tabular crystals of a blue color. They vary in size from very minute to half an inch in diameter and are of gem quality. The mineral does not occur in sufficient quantity to constitute a source of corundum for abrasive purposes, but it is of importance as a source of the sapphire gems.

A kersantite described by Dr. K. A. Lossen,[19] which cuts sedimentary rocks of Lower Devonian age at Michaelstein, in the Harz Mountains, Germany, and contains numerous inclusions, has also been found to carry corundum. This seems to be a closely parallel case to the one described above, except that the corundum occurs in such minute quantities as to be of only scientific interest.

CORUNDUM IN CRYSTALLINE LIMESTONE.

Corundum has long been known to occur in the white crystalline limestone of Sussex County, New Jersey, as near Sparta, in Newton Township, and near Vernon. It is found near dikes and bosses of intrusive granite, and is in the form of hexagonal crystals and irregular grains and masses of various colors—white, blue, red, purple, etc. Associated with it are spinel, chondrodite, phlogopite, graphite, ilmenite, rutile, sphene, zircon, and many other minerals. In the northward extension of this limestone into Orange County, New York, corundum is again found near Amity with practically the same relations. The contact phenomena of the granite of Mounts Adam and Eve, in Orange County, are described by Prof. J. F. Kemp and Mr. Arthur Hollick.[20] Numerous silicates occur in nodules or disseminated through the limestone: hornblende, dark mica, augite, titanite, scapolite, chondrodite, spinel, and fluorite, with occasionally sussexite, vesuvianite, tourmaline, and corundum.

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[18] Am. Jour. Sci., 4th ser., Vol. IV, 1897, pp. 421-423. and Twentieth Ann. Rep. U. S. Geol. Survey, Pt. III, 1900, pp. 552-553. Prof. Pirsson has kindly gone over the manuscript describing this occurrence.

[19] Zeitschr. d. Deutschen geol. Ges., XXXIII, 1880, p. 445; XXXIV, 1882, p. 658.

The crystalline limestones of Burgess Township, Lanark County, Onario, Canada, also contain small grains and crystals of rose-red to sapphire-blue corundum in association with quartz, feldspar, calcite, muscovite, sphene, etc.

Dr. A. Lacroix[21] has described the occurrence of corundum with humite, brucite, amphibole, phlogopite, scapolite, spinel, sphene, rutile, zircon, and other minerals, in the marbles of Mercus and Arignac, Ariege, France. Red and blue corundum has also been found associated with tourmaline in the dolomite at St. Gothard; and the extensive occurrence of large irregular masses of emery in the white crystalline limestone of the province of Aidin, in Asiatic Turkey, are well known.

MODES OF OCCURRENCE OF CORUNDUM NOT FOUND IN AMERICA.

A number of foreign occurrences of corundum, especially those that are of economic importance, have been referred to above in connection with descriptions of similar occurrences in America. There are, however, several other modes of occurrence of corundum of scientific interest that have been observed in foreign localities but have not yet been found in America. These are briefly mentioned here, in order to make the list of known modes of occurrence as nearly complete as possible. And here, as in the descriptions of American occurrences outside of North Carolina, there is no attempt to give a complete list of localities.

Corundum-bearing rocks not found in North America.

IGNEOUS.

Kyschtymite.
Diorite.
Tonalite.
Gabbro.
Quartz-porphyry.
Trachyte.
Basalt.
Contact-zones and inclusions in igneous rocks.

METAMORPHIC.

Corundum-schists and porphyroids.
Graphite.

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[20] Ann. N. Y. Acad. Sci., Vol. VII, 1893, pp. 638, et seq.

[21] Bull. Serv. de la Carte geol. de France, Vol. II, No. 11; Am. Nat., 1891, pp. 138-139 (abst.).

In various places throughout the Urals there are numerous orthoclase-corundum rocks that have been classed as pegmatites and syenites; and from among these Morozewicz has differentiated what he considers a new type, and has given it the name kyschtymite after the Kyschtym district of the Urals.[22] The rock is medium grained and is composed of idiomorphic corundum of a pyramidal habit, anorthite, and biotite, with accessory dark-green spinel, apatite, and zircon.

Teller and von John[23] found corundum associated with tourmaline, spinel, ilmenite, rutile, biotite, and occasionally zircon in the borders of quartz-mica-diorites that penetrate the gneisses and schists at Klausen, in southeastern Tyrol. The same minerals were also found associated in the contact zones of the schists and gneisses. The corundum is in colorless or bluish crystals of microscopic dimensions, only the tourmaline, in fact, being visible to the naked eye.

Dr. Zirkel[24] notes the occurrence of corundum in the tonalite of the Eifel, Germany.

Drs. Andræ and König[25] describe an extremely basic facies of saussuritic hornblende-gabbro at Frankenstein, Germany, in which masses and streaks of magnetite, sillimanite, and tabular crystals of colorless corundum occur in large allotriomorphic plagioclase feldspars. In every way comparable to this is the occurrence of nodules and masses of spinel and corundum in coarse irregular feldspars in the somewhat amphibolized gabbro of Veltlin, Germany, described by Linck.[26] Attention has already been called to the similarity of these occurrences to the spinel-emery in the norites of the "Cortlandt series" of eruptives, in Westchester County, New York.

Probably the only instance of corundum in quartz-porphyry that has been observed thus far is that described by von Foullon[27] from Teplitz, in Germany. After subjecting the rock to the action of hydrofluoric and sulphuric acids an insoluble residue was obtained consisting of small grains of corundum.

Hussak[28] describes corundum from the trachytic bombs of the volcanic region of the Laacher See, in Germany. Pohlig[29] found green corundum in a bomb from the trachyte-tuffs of Königswinter; and Dana[30] mentions a similar occurrence in bombs at Niedermendig.

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[22] Tschermak's Min. u. Pet. Mittheilungen, Vol. XVIII, Pts. 1-2-3, 1898, and Review of same in Jour. Geol., Vol. VII, p. 304, 1899.

[23] Jahrb. k. k. geol. Reichsanst., Vol. XXXII, 1882, pp. 589-684.

[24] Lehrbuch der Petrographie, Vol. I, 1893, p. 416.

[25] Abh. Senck. Ges. Frankfurt, 1888, p. 62.

[26] Sitzungsber. Akad. Wiss. Berlin, Vol. VI, 1893, p. 47.

[27] Verh. geol. Reichsanstalt, Vienna, No. 8, 1888, p. 178; Am. Nat., 1889, p. 524 (abst.).

[28] Sitzungsb. Akad. Wiss. Wien, Vol. LXXXVII, 1883, p. 358.

[29] Sitzungsb. niederrhein. Ges., Bonn, May 7, 1888.

Besides the occurrence of corundum in metamorphosed inclusions in the volcanic rocks of the Auvergne, France, Dr. Lacroix[31] also found the mineral extensively in the rocks themselves; trachytes, andesites, basalts. Similar mineral associations, both in the inclusions and in the volcanic rocks, are described by Dannenberg[32] in the trachytes, andesites, and basalts of the Siebengebirge, Germany.

Corundum in zones of contact-metamorphism has been observed at various American localities, particularly in the crystalline limestones penetrated by granites in New York and New Jersey, as described under American occurrences, above. Busz[33] has also observed corundum as a contact product of granite on clay slate at Dartmoor, in Devonshire, England. Barrois[34] describes banded violet and green hornstones produced by metamorphism in granite at Pont-Paul, near Morlaix, in Finisterre, France. The violet layers consist of biotite, magnetite, pleonaste, corundum, andalusite, staurolite, quartz, and pyrite, and are thought to have been originally a highly aluminous shale.

As a contact product on nepheline-syenite, Raysay[35] has described corundum from the Kola Peninsula, Archangel government, Russia. A massif of nepheline-syenite occurs in Umptek, with border facies comparatively free from nepheline (umptekite). On the east side this rock is bordered by sillimanite-gneiss, between the layers of which the syenite is intruded in sheets of variable thickness down to microscopic dimensions; but in all cases the boundaries of the two rocks are clearly defined. The gneiss contains, besides sillimanite, zoisite, garnet, spinel, corundum, and magnetite. The last three occur in elongated masses in quartz-feldspar aggregates.

Salomon[36] found corundum in the phyllites metarmorphosed by quartz-mica-diorite and tonalite in the vicinity of Mount Adamello, in the Alps of Lombardy, Italy. The phyllites have been converted into hornstone containing cordierite, andalusite, sillimanite, tourmaline, spinel, zircon, corundum, and other minerals. Some layers of the rock are rich in corundum.

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[30] System of Mineralogy, 6th ed., 1895, p. 212.

[31] Sur les enclaves acides des roches volcaniques de l'Auvergne, Paris, 1890; Bull. Soc. fr. de Min., Vol. XIII, 1890, pp. 100-106; Am. Nat., 1891, p. 140 (abst.); Mem. Ac. Sci. de l'Inst. de Fr., Vol. XXXI; Am. Nat., 1895, p. 657 (abst.).

[32] Min. und Petr. Mitth., Vol. XIV, 1894, p. 17; Am. Nat., 1894, pp. 946-947 (abst.).

[33] Geol. Mag., Vol. III, 1896, pp. 492-494.

[34] Bull. Soc. geol. de France, Vol. XIV, 1886, p. 888.

[35] Fennia, Helsingfors, Vol. XI, 1894, pp. 2, 77, 197.

[36] Zeits. deutsch. geol. Ges., Vol. XLII, 1890, p. 450; Min. und Petr. Mitth., XII, 1892.

Molengraaf,[37] in an account of the geology of the gold fields about Pretoria, in South Africa, describes the oldest rocks as granites, sericite-schists, actinolite-schists, and amphibolites. Above these lie quartzites, clay-slates, corundum-schists and porphyroids, and chiastolite-schists, cut by diabase dikes. The corundum-porphyroid resembles feldspar porphyry, consisting of large crystals of biotite and large corundum individuals in a groundmass of quartz and chlorite.

Wichmann[38] describes corundum from the graphite of Muhldorf, near Spitz, in Lower Austria. Scales of graphite are found with corundum in the peridotites at the Bad Creek mine, Sapphire, Jackson County, North Carolina, and are often associated with the corundum of the mica-schists of the State. Surface specimens of corundum found in a region of garnetiferous mica-schists 8 miles northwest of Gaffney, South Carolina, sometimes have scales of mica and graphite attached to them; but the Austrian occurrence seems to be the only instance thus far observed where the corundum is imbedded in graphite.

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[37] Neues Jahrb. Min., etc., B.-B. Vol. IX, 1894-5, pp. 174-291; Am. Nat., 1895, pp. 470-471 (abst.).

[38] Verh. geol. Reichsanstalt, Vienna, 1884, p. 150.

CHAPTER VIII.

THE DISTRIBUTION OF CORUNDUM.

As has been shown in Chapter VII, corundum occurs in various forms and relations, and instead of existing in quantity only in the basic magnesian rocks, such as peridotites, as was formerly supposed, it is now known to occur in large amount in syenites, gneisses, and schists. With the exception of a few localities in Montana, two in Colorado, and one in California, all the known occurrences of corundum in the United States are confined to the Appalachian belt of crystalline rocks.

CORUNDUM IN THE APPALACHIAN BELT.

In describing the distribution of the peridotites, mention has already been made of the occurrence of corundum in Pennsylvania, North Carolina, South Carolina, Georgia, and Alabama. In these States the corundum localities are found for the most part along the peridotite belt indicated on the general map (Plate IV). It is in the southern portion of this belt, in North Carolina and Georgia, that these rocks have their greatest extent, and in this region the greatest quantity of corundum has been found. During the past few years the only States that have produced corundum for abrasive purposes are North Carolina and Montana. Massachusetts and New York are the only ones that have produced emery.

Alabama.[1]—The Appalachian crystalline belt passes under the Cretaceous and later sedimentary formations in the central part of the State near Montgomery. Representatives of the peridotite belt have been found in the vicinity of Dudleyville, Tallapoosa County, and corundum has been found in fragments on the surface both in this and Coosa, the adjoining county on the west. No corundum has yet been found in place, but it evidently originated in the peridotites. But little prospecting has been done, and no workable deposit has been found in the State.

Georgia.[2]—A series of scattered outcrops extends the peridotite belt through this State in a northeast direction, passing in a general way up the valley of the Chattahoochee River to the western extremities of North and South Carolina. Along this line corundum has been found in the following counties: Rabun, Towns, Union, Lumpkin, Habersham, Hall, Cobb, Paulding, Douglas, Carroll, Heard, Troup, and somewhat off the line to the east, in Walton. In Forsyth County, surface specimens have been found that evidently originated in the quartz-schists of the region. Surface specimens of corundum that originated in a mica-schist have been found in Upson County. Considerable work has been done along this belt, most of it in the nature of prospecting.

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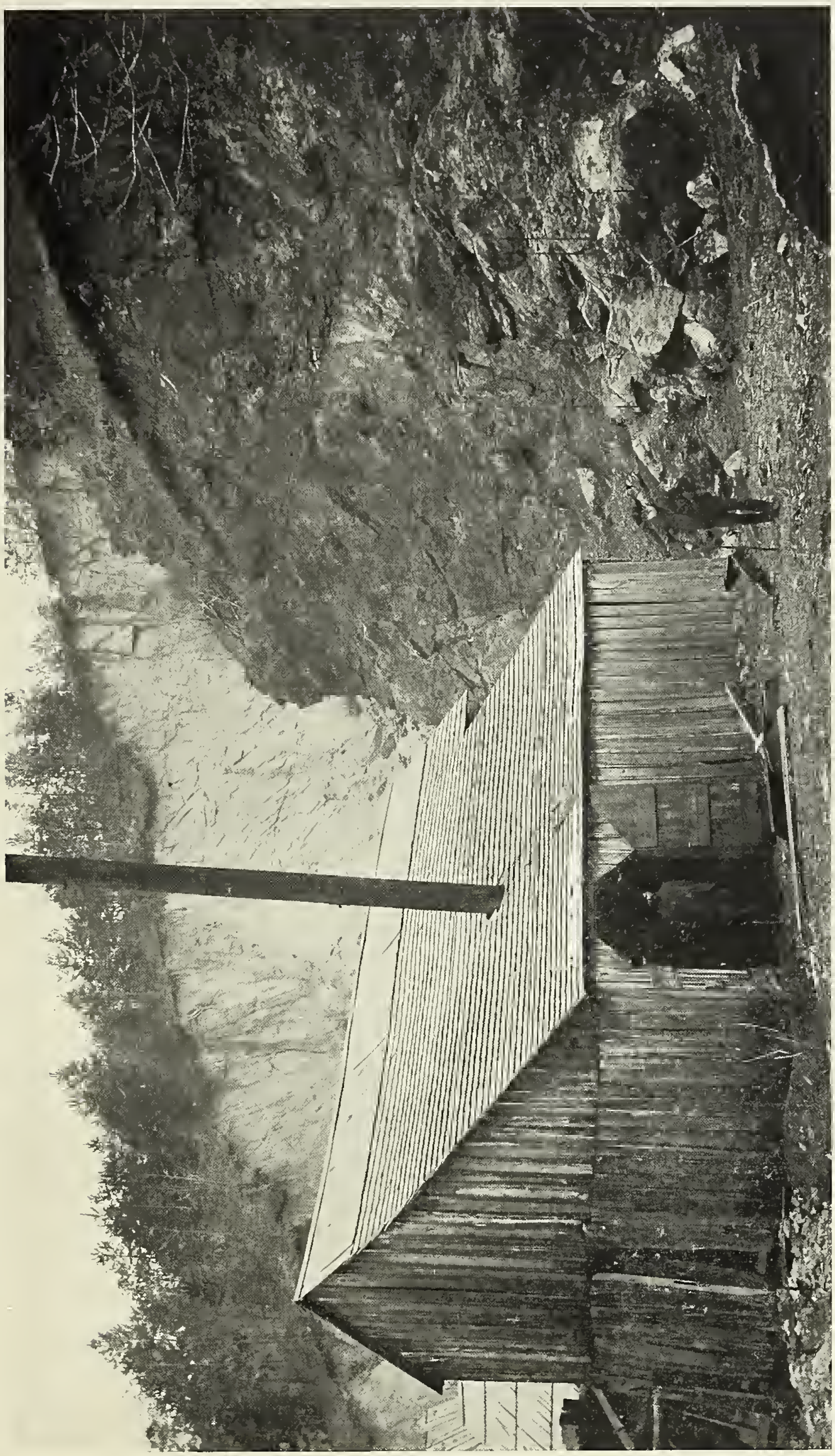
[1] E. A. Smith, Geol. Survey Alabama, 1874, W. M. Brewer, Geol. Sur. Ala., Bull. No. 5, 1896; E. A. Smith and Henry McCalley, Geol. Sur. Ala., Min. Resources, 1904, p. 60; and J. H. Pratt, Bull. U. S. Geol. Survey No. 180, p. 79.

[2] F. P. King, Bull. Geol. Survey Georgia No. 2, 1894, and J. H. Pratt, Bull. U. S. Geol. Survey No. 180, pp. 63 and 80.

Georgia corundum is well known, and perhaps has the best reputation of any on account of that obtained from the Laurel Creek mine, which, with the exception of the Track Rock mine, is the only one that has produced corundum in considerable quantity. The peridotite formations are smaller, the corundum localities less numerous, and corundum is probably less abundant than in North Carolina, although that from the Laurel Creek mine may be superior to any thus far found in the latter State.

This mine, owned by the International Corundum and Emery Company, is located at Pine Mountain, Rabun County, Ga., 18 miles from Walhalla, S. C., which is the nearest point on the railroad. At this locality there is a large outcrop of peridotite, covering several hundred acres, and near the contact of this with the gneiss large deposits of corundum have been found. Several openings have been made, some of which have been worked very extensively. The formation extends over two small hills, which, on account of their rough and barren nature, offer a sharp contrast to the surrounding country. On the west side of the formation, a large open cut has been made, which extends for the most part along the contact, is 200 feet in depth at the lower end, and gradually rises until at the upper end the surface is reached. At its lower end this cut encountered what is known as the Big vein of massive corundum, the cut having followed on a border vein of crystal corundum. Pl. XXIII is a reproduction of a photograph of this cut, which shows the gneiss on the left, the peridotite on the right, and the shaft house in the foreground.

The Big vein of massive corundum, for which this mine is noted, is at the foot of the south slope of the hill, and has been followed from the lower end of the big cut for a distance of over 300 feet. Although this vein is near the contact of the peridotite with the gneiss, it is separated from the latter by a band of peridotite and a small vein of sand corundum. There is some doubt whether this gneiss is entirely or



OPEN CUT ON PERIDOTITE-GNEISS CONTACT AT LAUREL CREEK, RABUN COUNTY, GA.

only partially surrounded by the peridotite. From what could be seen, and from information obtained from Mr. Andy Evans, foreman of the mine, it seems very probable that it is entirely enclosed in the mass of peridotite. The Big vein, which has been worked by an inclined shaft 116 feet deep, with tunnels 300 feet in length running from this, has brought the work up to the block of gneiss just referred to, and, according to Mr. Evans, a little work was done farther to the east which showed that the corundum vein extends beyond the south side of the block of gneiss. Open cuts on the east and west sides of this block of gneiss have followed border veins of corundum. Little work has been done at Laurel Creek except on border veins, the principal exception being a small interior vein near the east end of the formation, from which considerable corundum was obtained, but the vein soon began to pinch out (Pl. XX, B).

This is perhaps the most famous corundum mine in this country, and has furnished ore from which an exceptionally good commercial product has been obtained.

It has not been worked since 1894, when the tunnels and shafts of the Big vein were cut off by the slipping of a large block of the peridotite, nearly a 200-foot cube.

The Track Rock mine is in the northeastern part of Union County, Ga., on the south side of Track Rock Gap. The corundum occurs in a peridotite formation, which is very much decomposed on the surface, there being very little visible but a mass of chlorite-schist containing more or less actinolite. A tunnel whose upper end is 75 feet below the surface has been run in on the formation for about 200 feet, with short branching tunnels at several points. From the material cut through by the tunnel, which was examined by Mr. Francis King,[3] of the Georgia Geological Survey, the rock was found to be an altered peridotite, made up of small grains of chrysolite surrounded by actinolite, and containing many grains of magnetite. It is probable that the original of this rock was amphibole-peridotite.

All the work that has been done at this mine has been entirely within the formation, yet the best results would be expected near the contact of this rock with the surrounding country rock.

South Carolina.[4]—Corundum is found in Laurens, Anderson, Oconee, York, and Spartanburg counties. The western portion of this State is in the line of peridotites as indicated by the direction of the belt in

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[3] Bull. Geol. Survey Georgia, No. 2, 1894, p. 93.

[4] S. C. Resources, etc., State Board of Agr., 1883, p. 137, and J H. Pratt, U. S. Geol. Sur., Bull. 180, pp. 66 and 87.

Georgia and North Carolina, and these rocks are known to exist along the border in the northwestern corner. But little work has been done, however, to trace out their distribution or to locate any corundum deposits that may exist.

In the northeastern part of York County, from 3 to 4 miles west of the Catawba river, on the land between Allison and Crowder creeks, corundum has been found in a belt about 200 to 300 yards wide which skirts along the western slopes of Nannies mountain. This locality is about 12 miles northeast of Yorkville, S. C., and 25 miles southwest of Charlotte, N. C.

Mining operations have been carried on at two distinct portions of this belt, one a mile north of the summit of Nannies mountain, on the property of Mr. Alexander Rickard. The work done here consists of a shaft about 35 feet deep, from which several drifts have been run, that penetrate a light-gray granitic rock which is much decomposed and of a sandy constituency. The only solid material encountered consisted of irregular masses of black cleavable corundum associated with muscovite mica. In the surrounding fields float corundum, ranging in size from small particles to masses of several pounds in weight, is abundant, and many tons of this have been picked up and shipped.

A little west of the south end of Nannies Mountain, about 1½ miles from the Rickard mine, there is a similar occurrence of corundum. There have been a number of shallow cuts, ditches, and pits made in prospecting for corundum, but apparently none was found in place. The rock at this place is a typical light gray granite, and is exposed in considerable ledges. The corundum that was found is often wrapped in mica. The source of the corundum is unquestionably the granitic rock, as described on page 222.

North Carolina.[5]—As remarked above, this State presents the greatest development both of peridotite and corundum. The belt here attains its greatest width, and the largest outcrops of peridotite rocks in the Atlantic States are found in the southwestern counties. As indicated on the map (Pl. II), corundum occurs in Clay, Swain, Macon, Jackson, Haywood, Transylvania, Buncombe, Madison, Yancey, and Mitchell counties along the belt of basic magnesian rocks; and it is found east of the mountains in the counties of Cleveland, Burke, Gaston, Alexander, Iredell, and Guilford. These localities are described in detail beyond (pp. 239-264).

Virginia.[6]—Thus far corundum has been reported from only three localities in Virginia. The first is in Louisa County, where a large deep-blue crystal was found by Mr. Louis Zimmer, and reported by Mr. George F. Kunz. The second is that described by Dr. F. A. Genth[7] in 1890, and noted in describing the mode of occurrence in gneiss (Chapter VII). The peridotite belt is continued through the State by a great number of peridotite, talc and serpentine outcrops, but no corundum has been reported from any of these localities. The third locality is near Whittles, Pittsylvania County, where an emery variety of corundum was found.

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[5] J. V. Lewis, Geol. Survey North Carolina, Bull. No. 11, 1896, and J. H. Pratt, U S. Geol. Survey, Bull. No. 180, p. 55.

[6] Min. Res. U. S., 1883-4, p. 736, U. S. Geol. Survey.

Maryland.—The peridotite belt is well represented in this State, but no definite information can be obtained that any corundum has been found, beyond a stray surface specimen reported to have been picked up in the vicinity of White Hall.

Pennsylvania.[8]—The serpentine belt that comes diagonally across Maryland, is continued in Pennsylvania through the counties of Lancaster, Chester, Delaware, Montgomery, and Bucks. Corundum is associated with the serpentine rocks of this belt in many places, especially in Chester and Delaware counties, and was mined to a certain extent in Chester County in 1891 and 1892. It occurs here somewhat sparingly in chloritic zones near the borders of the serpentine, but is also found in larger amounts associated with granular albite, the occurrence being similar to that at Buck Creek, Clay County, North Carolina. Fine crystals of asteriated corundum, associated with feldspar, tourmaline, and spinel, have also been found near Shimersville, in Lehigh County.

Delaware.—Corundum has been found very sparingly in this State in the serpentine rocks, in the vicinity of Chandlus Hollow, New Castle County, and near the Pennsylvania border.

New Jersey.—The crystalline belt disappears under the Jura-Trias near Trenton, almost immediately on crossing the Pennsylvania line. Portions of it outcrop again farther north in the Highlands, but it does not reappear in the line of the peridotite belt till we find it on the opposite side of the State at Hoboken, where serpentine is found, but no corundum. Corundum is found, however, in Sussex County, along the borders between the crystalline limestones and the gneiss.

New York.[9]—Blue and white corundum has been found in the limestone, near Amity and Warwick, Orange County, the occurrence being similar to that in New Jersey (see p. 226).

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[7] Am. Jour. Sci., Vol. XXXIX, 1890, p. 47.

[8] F. A. Genth, 2d Geol. Sur. Pa., B, 1875, p. 31; and J. H. Pratt, Bull. U. S. Geol. Survey 180, pp. 66 and 86.

[9] Bull. U. S. Geol. Survey No. 180, p. 70; and J. F. Kemp and Arthur Hollick, Ann. N. Y. Acad. Sci., Vol. VII, 1893, p. 638.

Emery deposits are associated with norite rocks in Westchester County, described on page 225. Deposits of magnetite and emery have been found at a number of places 3 to 4 miles southeast of Peekskill. These vary considerably in character, some being a nearly pure magnetite, others containing magnetite and spinel, and still others magnetite, spinel, and corundum. Those within a mile north and northeast of Crugers station have been worked for iron ore, while those worked for emery are in the southeastern part of Cortlandt Township. The principal openings have been made on a ridge running north from Colabaugh Pond, and it is here that the ore has been mined. While the iron ore and emery appear to be very rich, it was found on examination that there was mixed with the magnetite more or less dark-green mineral, which Dr. George H. Williams[10] has shown to be the pleonaste variety of spinel. There is also considerable spinel in the emery, and even when this is abundant the emery cannot be distinguished in the hand specimens from that in which there is almost none of this mineral.

At the emery deposits in the southeastern part of Cortlandt Township the percentage of corundum varies considerably at different openings. It is sometimes observed in small blue, white, and colorless crystals. Spinel is associated with most of the corundum, and much of the material that has been mined for emery contained little or no corundum, but consisted of magnetite and spinel. This material has most of the requisite properties of a true emery except the high degree of hardness due to the corundum; and when made up into a wheel it would not be expected to possess the cutting efficiency of a true emery wheel. The spinel, which is 8 in hardness (corundum being 9), would play the same part in this that corundum plays in the true emery, and while not so hard as corundum, it has cutting qualities that would give the material considerable value as an abrasive. For many purposes wheels made from this could be used fully as well as emery or corundum wheels and for some purposes they might be used to better advantage. The spinel would not interfere in the manufacture of a vitrified wheel. Some of the material mined here carries a very high percentage of garnet.

Connecticut.—Connecticut has thus far furnished only surface specimens of corundum and no deposits of commercial importance. Early in the last century a mass of cyanite was found at Litchfield, "associated with talc. sulphuret of iron, and corundum—reported to weigh 1500 pounds."[11] It has also been sparingly found with sillimanite in the vicinity of Norwich. A peculiar occurrence of corundum has recently been described by Prof. B. K. Emerson[12] as occurring at Barkhamsted, Litchfield County. It is granular, resembling somewhat Ceylon emery, and of a dark-blue to blue-black color with occasional patches of a pistachio-green color. Under the microscope it is seen to be composed of elongated grains, throughout which are scattered small, stout prisms of cyanite and is penetrated through and through with grains and rounded balls of a coaly substance. According to Prof. Emerson:

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[10] Am. Jour. Sci., 3d series, Vol. XXXIII, 1882, p. 194.

[11] Edward Hitchcock, Am. Jour. Sci., Vol. VI, 1823, p. 219.

> This carbonaceous matter has been evidently introduced in an oily or tarry condition, and has been inspissated in place; and the abundant graphitic matter in the garnet gives indication of the same origin.

The rocks with which the corundum is associated are cyanitic mica-schist and fibrolite-gneiss. In the latter rock are found the garnets coated with graphite which are mentioned above.

Massachusetts.—Near Pelham, in this State, corundum has been found in a zone of biotite along the contact of harzburgite (saxonite) on gneiss. Incidental to the mining of asbestos at this locality, several tons of corundum ore were taken out and shipped. The deposit has not developed into one of economic importance (see p. 205).

The most noted deposit in this State is the emery vein at Chester (see p. 360). This occurs in a band of amphibolite near its contact with a sericitic schist on the east. The emery vein can be followed for a distance of nearly 5 miles, starting from where it is first encountered at the north end of the broad band of amphibolite on the left bank of Westfield River, just beyond the bridge of the Boston and Albany Railroad. The general strike of the vein is a little east of south, and extends for the most part parallel to the line of contact of the amphibolite and schist. Emery is not found throughout the entire length of the vein, but this can be almost continuously followed by means of streaks of chlorite. The vein varies in thickness up to 10 or 12 feet, the emery having an average thickness of about 6 feet. On both sides of the emery there are usually thin seams of chlorite, varying from 1 to 6 or more inches in thickness.

These deposits have furnished the larger part of the emery mined in the United States.

CORUNDUM IN THE WESTERN PART OF THE UNITED STATES.

As was stated above, corundum is authentically known only from Montana, Colorado, and California, although it has been reported from Nevada and Utah. The occurrences are very different from those in the eastern part of the United States and but one of them is associated with basic rocks somewhat similar to peridotite.

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[12] Am. Jour. Sci., Vol. 14, 1902, pp. 235-236.

Montana.[13]—Sapphire corundum occurs at many localities in this State, which have considerable economic importance as a source of supply of gems. At Yogo Gulch, Fergus County, blue sapphires are found in basic monchiquite. At many of the bars on the Missouri River, east and northeast of Helena, sapphires of various colors are found which have probably originated in an andesite (see page 224). In the gravels of Rock Creek, Granite County, many handsome sapphires of nearly all colors have been found.

In the south-central portion of Gallatin County, about 23 miles south of Belgrade, corundum for abrasive purposes has been found in commercial quantity. It occurs in a syenite rock, which is described on page 222. This property has been developed by pits and crosscuts, and these show the deposit to be very persistent and regular for 1000 feet, the distance that the work has been carried on. The property has been thoroughly equipped with machinery for mining, cleaning, and preparing the commercial corundum; and its product is now on the market. The tests that have been made on the finished products show that it has a very good abrasive efficiency.

Near Norris, Madison County, corundum of gem quality has been found by Mr. A. M. Tanner, in his concentrates from gold placer mining. One piece of corundum showing good red and green colors, weighed 8 ounces, and one piece of ruby color weighed 588½ carats.

Colorado.—At the Calumet iron mines, in Chaffee County, corundum crystals have been found in the mica-schists at their contact with intrusive dikes of diorite. Mr. R. C. Hills, Geologist to the Colorado Fuel and Iron Company, writes that it is a band of rock 6 inches to 2 feet thick that has been followed for a distance of 500 feet and that it averaged 40 per cent of corundum.

An interesting occurrence of corundum has recently been observed in Fremont County, Colo.,[14] about 7 miles from Canyon, the nearest railroad station. The corundum occurs in a matrix composed of quartz, plagioclase feldspar, and mica (muscovite and biotite). The maximum width that has been observed of this rock is 3 feet, and it has been traced for a distance of 3000 feet. The corundum is thickly scattered through the rock in small particles and fragments up to half an inch or more in diameter. It does not occur in good crystals, but some rough hexagonal prisms half an inch in diameter were observed. Its color varies from nearly colorless through a pale blue to a rather deep blue and is sometimes a pale green. There is but little development of parting planes in the corundum, and it shows on nearly all its exposed surfaces a rough conchoidal fracture. In the specimens that have been examined the quartz forms a considerable percentage of the rock, while the corundum sometimes appears nearly as prominent. The feldspars and micas are developed to a less extent. The corundum is transparent to semi-transparent, and some is of gem quality. No work has been done to develop the property.

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[13] Bull. U. S. Geol. Survey No. 180, p. 47.

[14] J. H. Pratt, U. S. Geol. Survey, Mineral Resources, Pamphlet on Abrasives, 1901, p. 45.

This adds another locality to the occurrences of corundum associated with feldspar in an acidic rock. The feldspar is not nearly so prominently developed in this rock as it is in the occurrences of corundum in syenite in Montana, and in Ontario, Canada. In the Canada occurrence the feldspar is an orthoclase; at the Colorado locality it is a plagioclase feldspar. The rock is granitic in character. The value of this deposit for abrasive purposes will depend upon the cost of the separation of the corundum. The quality of the corundum is good, and, as far as can be judged without making actual tests, it would make a good vitrified wheel. This property is now being investigated by Mr. Eugene Weston, of Canyon.

California.—A discovery of corundum has been made in Plumas County, Cal., about 1½ miles northwest of Meadow Valley. It occurs in a dike (plumasite) composed of feldspar and corundum cutting a mass of serpentine on the eastern flank of Spanish Peak at an elevation of about 4100 feet. The corundum occurs in crystals and rough fragments from blue to bluish-gray in color (see p. 223).

NORTH CAROLINA LOCALITIES IN DETAIL.

In a general way, the corundum localities of North Carolina are indicated on the map (Pl. II), except those of Gaston and Guilford counties. In the following enumeration of localities those west of the Blue Ridge will be considered first—beginning with Clay County, in the southwestern corner of the State—and afterwards, the localities east of the mountains.

CLAY COUNTY.

One mile south of Elf, on Shooting Creek, and 5 miles southeast of Hayesville, peridotite occurs within about a mile of the Georgia line, and corundum is found associated with it in its most southerly outcrops, on the property of Mr. W. C. Ledford (see fig. 1, p. 37). It occurs here in "sand veins" in scaly vermiculites; and, a little further north, it is found in a vein of feldspar and green chlorite, on the land of Samuel Hogsed. On the same property it is found intimately associated with a pure white to cream-white zoisite and surrounded with feldspar, sometimes forming very large masses. It is also in rounded nodules with rhombohedral parting highly developed, and surrounded with a variable coating of a white, compact margarite. Sometimes there are but very small grains of corundum left; the original mass having been almost completely altered to margarite.

In the vicinity of Elf are found a number of outcrops of a bright green amphibolite, and at one place at the side of the road near the post-office, the rock contains beautiful pink corundum nodules and grains, having the rhombohedral parting well developed. Corundum nodules of a rich deep-blue color also occur sparingly in this amphibolite. These are semi-transparent to transparent, and somewhat resemble a gem corundum.

The Behr mine is located at Elf, 5 miles east of Hayesville, on Shooting Creek. Both sand and massive corundum, with feldspar, are found here, in the same peridotite formation with which the amphibolites, just referred to, are associated. The mine was first opened in 1880 by Dr. H. S. Lucas, but was soon afterwards bought by Herman Behr and Company of New York. A steam cleaning plant was erected at the mine and considerable work was done, which was more of the nature of prospecting than mining. Several car loads of cleaned corundum are reported to have been shipped. The last work done at the mine was 1890. The location is not very favorable for mining, as it is in a low place by the side of a branch, which necessitated the constant use of pumps. The nearest shipping point on the railroad is 25 miles distant. There are practically no indications at this locality of the occurrence of corundum in large quantity.

Corundum has been found on the surface and ploughed up in fields along the continuation of the peridotite strip up Lick Log Branch almost to the gap between this and Tusquittah Creek.

Except a few loose surface fragments picked up near Shooting Creek post-office, no corundum has been found along the strip of dunite and talc that crosses the headwaters of Shooting Creek, until the slopes of Chunky Gal Mountain are reached, at Mr. Newton Penland's. From this point it has been found all the way up the mountain side to about half a mile east of the summit, where the dunite narrows to very small dimensions and finally disappears. The occurrence in feldspar predominates toward the point of this outcrop, and this is also found along with the sand veins and crystal corundum on the mountain side.

The Isbel mine is at the foot of the southern slopes of the Chunky Gal Mountain, and was formerly known as the Shooting Creek mine. It is on the headwaters of Shooting Creek and alongside of the Macon-Clay county road. The corundum occurs in an amphibolite dike, which is so badly decomposed that very little of its original structure remains, the only solid rock present being small nodular masses of the original rock (p. 207). The surrounding rock is also very much decomposed. On account of the tenacious character of the material enclosing the corundum, it is difficult to wash it out, for it becomes packed and clogs the rolls, even in a strong current of water. This deposit of corundum has been developed by means of a large open cut and some tunneling, but the amount of corundum exposed is very small and the prospect is not encouraging. A very extensive plant has been built at the mine by the Isbel Corundum Company, of New York. On the same property there is a series of small outcrops of dunite extending to the top of the mountain and a small amount of corundum has been found associated with many of them, but nothing that would indicate a commercial deposit.

About 3 miles east of Shooting Creek post-office, on the southern slope of Gross Ridge, just above Thumping Creek, a tributary of Shooting Creek, corundum has been found at a number of localities in gneiss (see p. 211). The corundum is in rounded nodules and in crystals that are often very flat with the prism not over a quarter of an inch long, known locally as "button corundum" (fig. 9, p. 165).

This corundum-bearing gneiss was mined in 1892, at Mr. Curtis Ledford's, where it is said, about 2 tons of corundum were obtained. Corundum is also found here in vermiculite, developed beside a dike of hypersthenite (see p. 72). Almost directly across the creek, on land belonging to Mr. C. C. Patterson, considerable prospecting was done and portions of the gneiss were exposed that were sparingly studded with corundum. Further up the creek, at the Walker mine, owned by Mr. R. P. Walker, about 6 tons of corundum were taken out in 1893. The occurrence is the same as that at Ledford's and Patterson's.

At the head of Muskrat Fork of Shooting Creek, and about half way up the side of Chunky Gal Mountain, corundum is found imbedded in garnet and brown scaly biotite, forming bands in the gneiss. During 1894-5, this locality, known as the Hooker mine, was worked by Mr. C. C. Foster of Boston. A few hundred tons of corundum rock were taken out. The percentage of corundum is very low, and the fact that it is so intimately associated with garnet would prevent its being of any considerable value. None of this ore has been shipped or cleaned. (Pl. XXI, A.)

Long bands of corundum-bearing quartz-schist have been located in what may be called the Blue Ridge corundum tracts in the southeastern part of this County and in the adjoining Rabun County, Georgia. Parallel bands of this schist have been followed for a number of miles nearly to the summit of the Chunky Gal, Yellow, and Scaly mountains. As is stated on page 216, the percentage of corundum in these rocks is probably not over 5 per cent.

Under this head are included those areas of similar corundum-bearing rock known as the Scaly Mountain, Foster, Yellow Mountain, and Chunky Gal tracts.

The Scaly Mountain tract is on the southern and southwestern slopes of the mountain, at an elevation of about 4500 feet, near the headwaters of Beech Creek, a prominent eastern tributary of the Tallulah River. The corundum-bearing band of schist has been traced for a distance of about 2 miles. The general strike of this is N. 40° E., and it dips westward at an angle of 20 to 30°. Experiments show that the amount of corundum in this schist is less than 5 per cent, although some specimens have yielded 12 per cent, but these were pieces broken off along the lamination of the schist, while the main mass from which they were obtained carried but a low percentage of corundum.

The Foster tract is wholly within Georgia, the North Carolina line being its northern boundary. Its occurrence is almost indentical with that at Scaly Mountain.

The Yellow Mountain tract is north of the Scaly Mountain tract, on the northern slopes of the Yellow Mountains. No prospecting has been done here but from the indications the occurrence is the same as at the other localities.

The Chunky Gal tract is at the summit, and along the western slopes of the Chunky Gal Mountains, near the headwaters of Sugar Cove Creek. With a few interruptions, the corundum-bearing schist has been traced for over 2 miles. The strike and dip are approximately the same as at the others. A number of pits and cuts have been made, from which considerable ore has been taken out and tested, and the reports show the percentage to be practically the same as at other localities.

The corundum bands of the schists on all the tracts vary considerably in width, some being not over a foot wide while others measure 18 feet. These wider bands, however, often include bands of normal schist. More or less garnet has been found associated with the corundum in these schists, which, if not separated, would prevent the commercial product from being used in the manufacture of a vitrified wheel.

From the extent of the corundum-bearing schist, it may be inferred that there is undoubtedly a large quantity of corundum in this section, but the low percentage of the corundum in the rock makes it doubtful whether it can be profitably mined.

The Corundum Mining and Manufacturing Company of Philadelphia worked these deposits on the Scaly Mountain and Foster tracts for a number of years (1900 to 1902). A complete plant for handling and cleaning the ore was installed, but only a few tons of corundum were prepared for market.

On the mountains forming the divide between Shooting and Buck creeks, corundum has been found at a number of places, but for the most part in small pockets, that give no indications that it may occur in quantity. In Riley Cove of Riley Mountain, on the land of Mr. John Hanson, about 1½ tons of pure white corundum were mined by Mr. Charles C. Foster, of Boston. One mass was found that weighed nearly 400 pounds. Nearly all of the corundum was surrounded by margarite. On account of the decomposition of the rock in which the corundum was found, the nature of its occurrence is not definitely known, but it is probably associated with peridotite rocks.

The most important corundum locality in Clay County is the Buck Creek region, where the corundum is associated with the largest compact peridotite area in the State, a topographic and geologic map of which is shown in Pl. V, together with the various openings that have been made for corundum. This mass of peridotite has been fully described on page 72. The locality is in the narrow Buck Creek Valley about 20 miles southwest of Franklin, Macon County, and 21 miles a little north of east of Hayesville, Clay County.

The principal mining has been done in connection with the main mass of the peridotite on both sides of Buck Creek, and this is known as the Buck Creek or Cullakeenee mine.

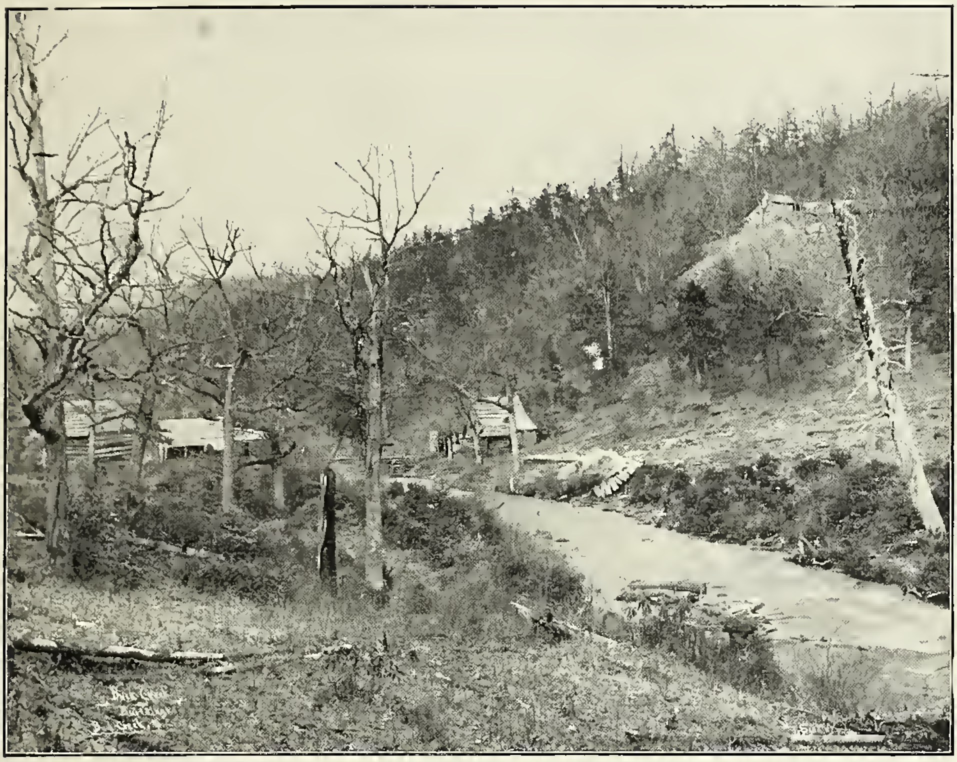
The first discovery of corundum at this locality was by Dr. C. D. Smith of Franklin, N. C. prior to 1875. Large loose blocks of corundum, associated with feldspar and hornblende, were found on the surface. The first prospecting was done by Major Bryson about 1875; and two years later Mr. Frank Meminger worked for six months, removing about 30 tons of corundum.

For a period of ten years no further mining operations were undertaken; then work was resumed by Mr. Ernst and continued for nine months, chiefly in the nature of prospecting. A number of pits and tunnels were opened, especially on the west side of the creek, and about 200 hundred tons of ore were taken out. During another period of four years, the mine was idle; then operations on a larger scale were begun by Mr. Gregory Hart, of Detroit, Mich., and continued for a year and a half, during which time the shaft was sunk on the border vein and several open cuts made on interior veins. Considerable quantities of corundum were taken out during this time, but none was shipped. Most of the product, however, was in large massive blocks associated with feldspar and black hornblende, and there was no means at hand for crushing and cleaning it.

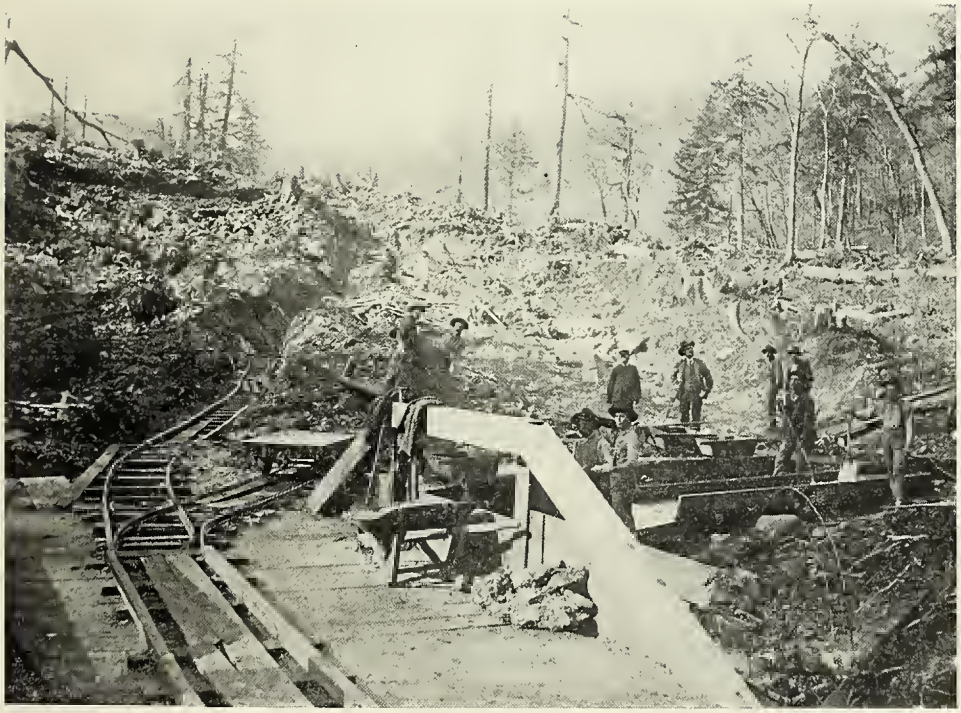
In 1893, the mine was purchased by the Hampden Emery and Corundum Company, and the material already mined was hauled to Corundum Hill and cleaned with the product of that mine. The mine is now owned by the International Emery and Corundum Company of New York. There has been but very little systematic mining for corundum at this locality, and most of the work that has been done was in the nature of prospecting. Numerous cuts and pits have been made at a great many points on the formation, most of which have shown the presence of corundum. The principal work has been done on the east side, near the contact of the dunite with the gneiss, where a shaft 40 feet deep was sunk partially on a border vein. From this shaft two tunnels were run, but they did not follow the main direction of the vein. A number of open cuts in this vicinity have penetrated into the same vein. This vein is different from most of the corundum veins in the peridotite rocks, in that it is composed essentially of corundum, plagioclase feldspar, and hornblende. Pl. XXIV, A, is a general view of the Buck Creek formation, showing the location of the shaft and the border vein that has been opened. With this exception, most of the pits and cuts that have been made are within the formation itself, and where they encountered corundum it has been in small pockets, which are the remnants of former interior veins. (See A of Pl. XX.) From the amount of corundum exposed by prospecting and by the work done in the shaft, there is without doubt a large amount of corundum associated with these peridotite rocks, and if the mine were more accessible to the railroad it would offer one of the best corundum prospects in the country. The nearest shipping point at the present time, however, is Murphy, which is over 40 miles to the west. The nearest point on the Murphy branch of the Southern railroad is only 18 miles, to which a good road can be built, which would not be so mountainous as the first 18 miles of the road to Murphy. Buck Creek offers a sufficient water supply for running a mill to clean the corundum.

In the green amphibolites lying between the peridotite and gneiss and

North Carolina
State Library.



A, GENERAL VIEW OF THE BUCK CREEK CORUNDUM MINES AND THE PERIDOTITE FORMATION, CLAY COUNTY, N. C.



B, CORUNDUM PROPERTY OF THE NORTH CAROLINA CORUNDUM COMPANY, BUCK CREEK, CLAY COUNTY, N. C.

penetrating the mass of the former, corundum of a delicate pink to ruby-red color is abundant. At the top of the ridge on the west side of the creek several tons were mined. On account of the refractoriness of the amphibolite it is not a profitable material to work.

Near the northwestern end of this peridotite mass, where it is much narrower than the main mass, is the Herbert mine, which is owned by the North Carolina Corundum Company of Detroit (Pl. XXIV, B). The corundum has been found in a number of small veins of almost massive corundum 3 to 6 inches thick. The main portion of the peridotite mass is farther east, and the largest deposits of corundum are probably associated with this mass. The company has developed this property quite extensively, and also another on the land of Mr. Marion Passmore, to the northeast, and erected a complete mill for treating the ore. During 1903 and 1904, this Company was the only one which produced any corundum. The corundum here is associated with a long apophysis running out from the main mass of the peridotite. One mass of yellow corundum weighing 125 pounds was also found in this vicinity on land belonging to Mr. Hugh Ferguson, of Pittsburgh, Pa.

MACON COUNTY.

CORUNDUM.

It was in this county that corundum was first mined in North Carolina, and from 1893 to 1900 it was the only county producing any corundum for market.

In the valley of the Little Tennessee River above Franklin there are a great many peridotite outcrops, most of which are indicated on the map, Pl. II. Emery has been found at a number of these places, but corundum, as far as is known, at only one. This locality is at the head of Hickory Knoll Creek, at an elevation of about 4000 feet, on the western slope of Fish Hawk Mountain. A number of small dunite outcrops are found here, and where these are exposed near the surface, they have a well-developed radial enstatite casing (Pl. XIV, A). A small amount of corundum has been found associated with them.

Six miles southeast of this, and just south of Mount Scaly, corundum has been found in small crystals and grains, with outcrops of soapstone and a fibrous, asbestos-like mineral. Radiating cases of talc, enclosing an ocherous, earthy material, are found here, representing the original peridotite, which is not now visible on the surface.

Near Coweeta, pink corundum has been found embedded in masses of a greenish cyanite, but none has been found in place.

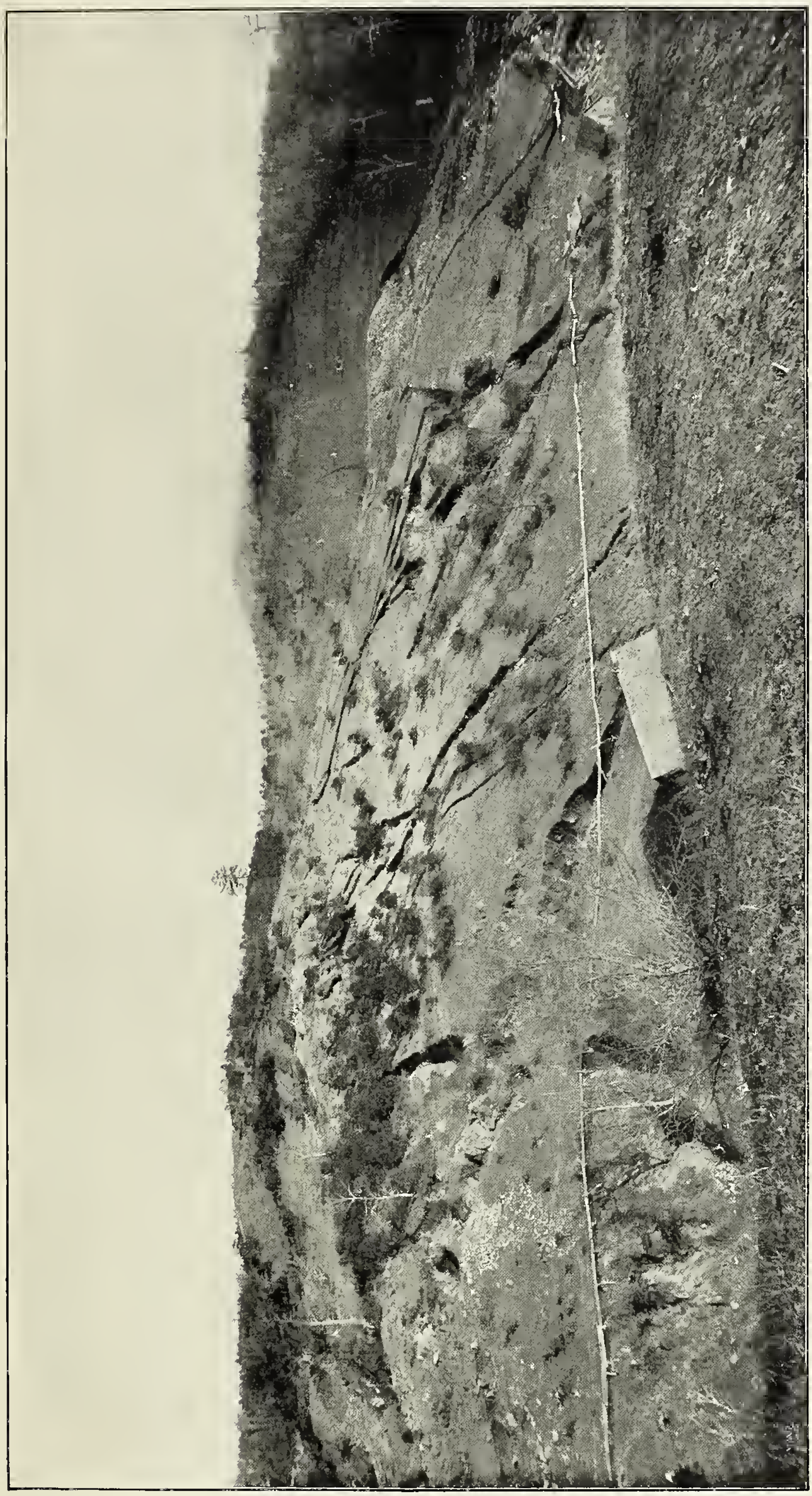
The most important corundum region in the mountain district lies 7 miles southeast of Franklin, just north of the Cullasaja River, and between Ellijay and Walnut creeks, two of its tributaries. On this, one of the most prominent western spurs of the Cowee Mountains, are found more promising corundum localities than in any other region of equal area within the State, or indeed, in the whole Appalachian crystalline belt. In this region, within a total area of less than 20 square miles, there are at least fifteen distinct areas of peridotite; and corundum in greater or less quantity has been found associated with nearly all of them.

Corundum Hill mine.—On the southern point of this spur is the Corundum Hill mine, which is the most widely known mine in the country and the one that has furnished by far the greater part of American corundum since the beginning of the industry.

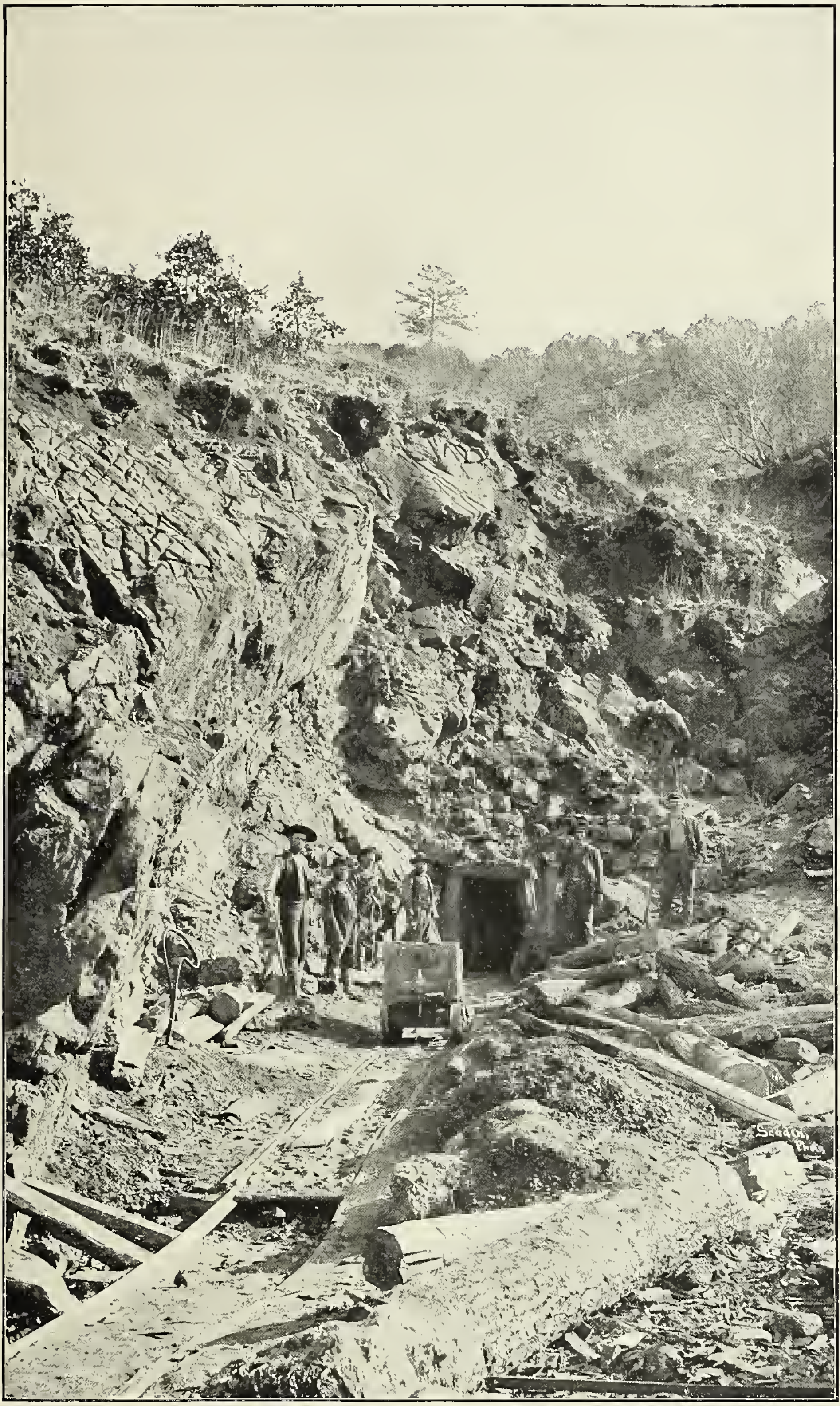
This mine is 7 miles southeast of Franklin, on Cullasaja Creek, a tributary of the Little Tennessee River. The post-office is Cullasaja. Since the beginning of active mining here in 1878, it afforded a constant annual product of 200 to 300 tons of cleaned corundum up to 1900; but since that time there has been but a small amount of corundum mined.

Work was begun here in 1871 by Col. C. W. Jenks, and there being then no precedent or guide in mining for corundum, many mistakes and failures were made during the first year. For instance, the value of sand corundum was not then realized, and the only material put on the market besides gems and cabinet specimens consisted of the larger crystals and pieces of massive corundum. About 100 tons of this material were mined, which was fully 90 per cent pure. This was sold to the S. S. White Dental Co. of Philadelphia, Pa., and to Pusey Jones & Co., of Wilmington, Del., and several small lots were sent abroad.

The corundum found at this mine occurs in a peridotite rock and has been worked very extensively, especially near the contact of this rock with the gneiss. Plate XXV is a general view of this peridotite formation and shows to a certain extent the number of openings that have been made in mining for corundum. The summit of this hill is about 500 feet above the level of Cullasaja Creek. Plate VI is a topographic and geologic map of this peridotite formation and shows the location of the various mines. It is a rather blunt, lens-shaped mass of dunite, covering an area of about 10 acres, over most of which the rock is exposed. As is seen from the map, most of the openings are located near the contact of the dunite with the gneiss or schist, along border veins of corundum.



GENERAL VIEW OF THE PERIDOTITE FORMATION AT CORONDUM HILL, MACON COUNTY, N. C.



ENTRANCE TO TUNNEL ON BIG VEIN, BETWEEN PERIDOTITE AND GNEISS, CORUNDUM HILL, MACON COUNTY, N. C.

A number of interior veins have been worked within the formation but with the exception of the one marked "Shaft" on the map, they have all soon pinched out; and they can be profitably worked only in connection with the large border veins.

Most of the mining has been done on the south side of the formation, where was encountered what is known as the "Big Vein." This was first mined by means of open cuts, and later by tunnels, the last one being about 300 feet below the summit of the hill. Plate XXVI is a view of the entrance to this tunnel, and shows the peridotite rock on the left and the gneiss beyond the cut on the right. For nearly the whole distance of the southern boundary of the dunite formation, a cut has been made, following the contour of the hill. This cut was sometimes wholly within the gneiss, at other times wholly within the peridotite, and again it was directly on the contact. The tunnels are all to the left of the cut, and they have encountered corundum almost continuously for a distance of 1280 feet, reaching almost to the southeast boundary of the formation. Plate XXVII is a view of the southeastern end of this cut, showing the peridotite on the left and gneiss and schist on the right. The upper part of this cut is known as the Stanfield mine. A tunnel has been run into the hill near the contact, and in places the vein of corundum was 8 to 10 feet wide. No work has been done at this point for a number of years.

On the northeast side of this formation is what is known as the Zeb Jones mine, in which there has been exposed a bench of ore 25 feet deep and 2 to 5 feet wide, uncovered for a distance of 50 feet, which averaged very close to 50 per cent corundum. This vein carries what is known as "buckwheat" corundum, which as its name suggests, is made up of small, irregular particles of corundum about the size of buckwheat grains (see B of Pl. XXI).

From the various openings, block, crystal, and sand corundum ores have been obtained, all of which can be readily cleaned and furnish a commercial product that can be used in the manufacture of any kind of corundum wheel. A small amount of garnet is occasionally found associated with the corundum in the vein near the southern contact, but this portion of the ore can readily be eliminated at the mine by hand cobbing.

The water supply at the mine is rather limited, but sufficient has been obtained to carry all the sand and gravel corundum to the mill in a line of sluice troughs a mile and a half in length. The rolling and scouring action to which the ore is subjected in going this distance does much toward separating the corundum from its accompanying impurities. The massive corundum is hauled to the mill in wagons, but as it is down grade practically all the way, the cost per ton for hauling is small. Cullasaja Creek furnishes all the necessary power for running the washing and cleaning machinery at the mill.

The Corundum Hill mine is owned by the International Emery and Corundum Company of New York, who also own the Buck Creek mine, in Clay County, N. C., and the Laurel Creek mine at Pine Mountain, Georgia.

At many of the other peridotite outcrops on the mountain between Ellijay and Walnut creeks, corundum has been found in greater or less quantity, and at two localities, the Mincey and Higdon mines, extensive mining was done several years ago.

The Mincey mine is located about 2 miles northeast of the Corundum Hill mine, 7 miles southeast of Franklin, and but a short distance above Ellijay Post-office. At this locality there is a considerable outcrop of peridotite (dunite), on a hill rising directly from Ellijay Creek. About 150 tons of corundum have been taken out of this mine by the Hampden Emery and Corundum Company which formerly owned the property. The main work consists of a large open cut in the midst of the formation, which was extended by means of a shaft and tunnel, the mouth of the tunnel being nearly on a level with the creek. Plate XXVIII is a view of this cut and shows its location entirely within the formation. Nearer the contact of the dunite with the gneiss another cut was made, in which some corundum was also found.

The amount of corundum mined and that found on the surface and near the contact of the dunite with the gneiss indicate that it exists in quantity along the contact. The corundum that was mined here was hauled in wagons, after partial cleaning, to the mill at Cullasaja. A considerable portion of it was crystal corundum of a peculiar bronze color, known locally as "pearl corundum."

Near by is the Moses mine, which was also worked by the same company for a short time. Neither of these mines have been operated since 1894.

Between the Corundum Hill and Mincey mines there is a bold outcrop of dunite, covering about the same surface area as that at Corundum Hill. No mining has been undertaken here, but prospecting has been carried on to a limited extent by sinking numerous shallow pits at various points within the formation, at many of which corundum was encountered. Numerous boulders and fragments carrying corundum have been found near the lower borders of the formation and in the stream beds. Although no large deposit has as yet been located, there are strong indications of the existence of a corundum deposit of considerable extent at the contact of the peridotite with the gneiss. This property is owned by Mr. John Gray, of Ellijay, Macon County. Corundum has also been found on the land between the Gray property and Higdon mine, belonging to Mrs. J. L. Robinson, of Franklin.

Near the summit of the mountain on which the Corundum Hill mine is located, but on the opposite or Ellijay side, is the Higdon mine. This mine was opened in 1895 by Mr. Chas. C. Foster, of Boston, and is now owned by the American Corundum Company.

The outcrop of peridotites at this locality is not large and a small border vein of sand corundum was opened. The gneiss wall is generally very sharply defined, while on the opposite wall are the alteration products of dunite which pass into the normal rock. The vein was opened by a cut and shaft about 100 feet deep. A mill was built at the foot of the mountain on the Ellijay road and the corundum was carried to it in troughs by gravity. A considerable quantity of the ore was cleaned but none has been shipped. This property has not been worked since 1896.

Considerable work in the nature of prospecting has been done at the New Mincey and the Haskett mines, which are further up the creek, the latter being nearly at the summit of the Blue Ridge, about one-half mile from Cullowhee Gap. Neither of these properties has yet shown any quantity of corundum. Two miles above the Mincey mine, and near the Cullowhee road, is the Jake Moore mine, where the little prospecting that has been done has shown the presence of what is apparently a border vein of corundum.

Near the foot of the eastern slope of the Nantahala Mountains, on the Buck Creek-Franklin road, a small amount of corundum was found in a saprolitic rock. Mining on a small scale was undertaken here by Dr. H. S. Lucas, and a little of the ore was hauled to his mill at Franklin. There is no indication of any large supply of corundum here. Near Nona post-office, 7 miles west of Franklin, well-formed corundum crystals have been found in the soil resulting from the disintegration of gneissic rocks. At the Raby mine, on Burningtown Creek, well crystallized corundum is sparingly found.

The Sheffield mine is in Cowee Township, about 7 miles a little northeast of Franklin, and about 1½ miles nearly east of West Mills. It is on the north side of Cowee Creek, on a hill rising 150 feet above the creek, and was operated by the National Abrasive Manufacturing Company of New York. The corundum occurs in an amphibole-schist which is described on page 216.

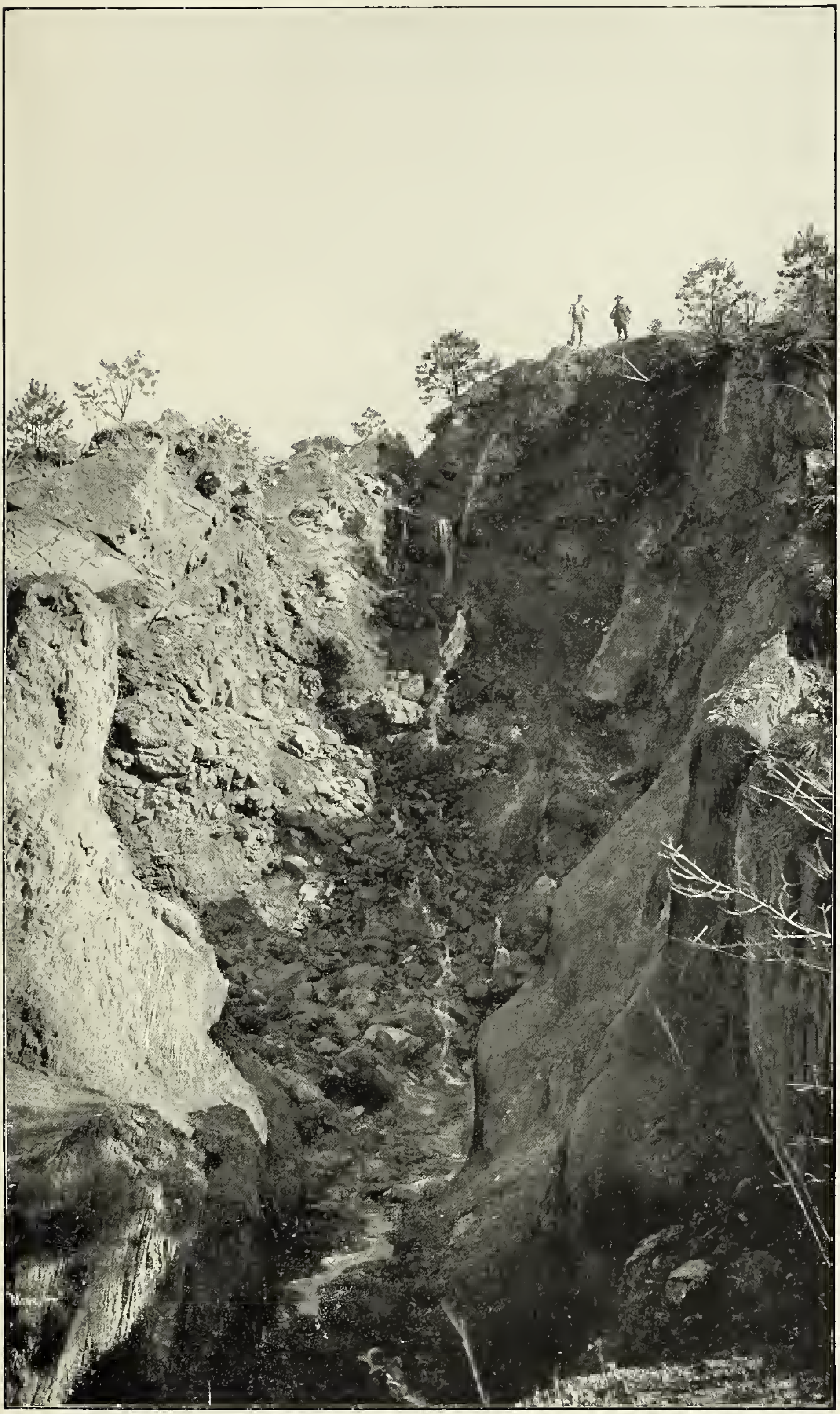
The corundum is in oval-shaped nodules up to an inch in diameter, of a pink and purplish color; it is of exceptionally good quality and high abrasive efficiency. It does not constitute over 3 to 5 per cent of the rock, although in the seams or bands in which it is more or less concentrated (see fig. 26) the percentage is as high as 10. Associated with the corundum are a pink almandine garnet, which at times forms a considerable per cent, pyrrhotite and chalcopyrite in very small particles or seams, sparingly disseminated through the rock, and also very sparingly, small scales of graphite. On account of the depth to which decomposition has extended, the solid rock was observed only in the lower portion of the 87-foot shaft and nothing definite can be stated as to the extent of this corundum-bearing rock. Practically all the mining that has thus far been carried on here for corundum has been in the decomposed (saprolitic) rock, and this has been done by means of tunnels and shafts. The corundum could be profitably mined in this saprolitic rock, although it forms but 3 to 5 per cent of the rock, but when the hard, tough, undecomposed rock is encountered, which carries more or less garnet, the problem will be altogether different, and it is not probable that it can be economically mined.

A small cleaning plant has been erected at the foot of the hill near the creek, which has a capacity of about 2 tons a day.

Red, ruby, and gray corundum has been found in the gravel beds of many of the creeks flowing into the Cowee. Some massive pieces, 1 or 2 inches in diameter, of a ruby-red corundum have been found on the William West farm, near West Mills. A region that has attracted much attention is in the valley of Caler Fork of Cowee Creek, where is located the Ruby mine of the American Mining and Prospecting Company, described on page 181.

At the Read or Watauga mine, which is 6½ miles east of Franklin, on the Dillsboro road, just above Watauga Creek, corundum has been found in a dike of saprolitic rock that probably was originally an amphibolite. The country rock is a hornblende gneiss, but in the immediate vicinity of the dike no solid rock is encountered. The general occurrence is somewhat similar to that at the Isbel mine, in Clay County, and at the Acme mine, in Iredell County. The corundum is in prismatic crystals ranging in size from that of buckwheat grains to nearly ½ inch in diameter. They are of an almost uniform pale bluish color and some are semi-transparent to transparent. The ore was readily cleaned and furnished a nearly pure product. The mill at this mine has a capacity of two tons a day. As at all the localities where the corundum occurs in an amphibolite, its quantity is very limited.

On the opposite side of Watauga Creek, 100 to 200 feet up the moun-



UPPER END OF CUT ON BIG VEIN, BETWEEN PERIDOTITE AND MICA-SCHIST, CORUNDUM HILL, MACON COUNTY, N. C.

tain slope, corundum has been found in gneiss and a number of shallow pits and short tunnels have been made in prospecting this occurrence; but no commercial quantity was exposed.

On the summit of Turkey Knob, on the Macon-Jackson county line, corundum has been found in gneiss, and some development work has been done. The property is owned by Mr. H. G. Turnbull, of Baltimore.

EMERY.

Emery has been found at a number of places in the valley of Little Tennessee River, south of Franklin. While nothing definite can be stated regarding the original rock in which the emery occurs, on account of the depth to which decomposition has extended, yet it has been classified as a saprolitic amphibolite (p. 206) on account of its similarity to decomposed amphibolites in other localities.

A number of outcrops of this emery-bearing saprolitic rock have been found about 5 miles southwest of Franklin. These, as far as could be judged, are isolated and in no way connected with one another. They are lenticular in shape and but a few hundred feet wide, the longer axis being sometimes two or three times this. While the general direction of the strike of these outcrops is approximately the same, they are not in a line with one another, but in a number of lines that are approximately parallel. The country rock through which these have penetrated is a hornblende-gneiss.

Considerable mining was done in 1898 at the Fairview mine, near North Skeenah Gap, by Dr. W. S. Lucas, of the Lucas Mining and Manufacturing Company, Franklin, N. C. About 100 tons of emery were obtained, which were cleaned in the mill at Franklin. The formation in which the emery occurs covers the top of Fairview Knob, the gneiss being encountered about 300 feet below the summit of the ridge. Emery has been found at a number of openings, particularly on the northwest side of the ridge. There is some staurolite associated with the emery, and in some respects this is similar to the occurrence at Hampton's, on Mine Fork, Yancey County.

One mile northwest of the Fairview mine, another excavation was made for emery on the southwest slopes of Dobson Mountain, on land belonging to Mr. J. A. Waldroop. A vein of emery ore 15 feet wide was exposed, but only a small amount was taken out.

To the south and southeast of Fairview mine similar deposits of emery have been found at Mr. William Mann's, three-fourths of a mile south, and at Mr. James Ledford's, 1¼ miles southeast, both of these properties were prospected by Dr. Lucas. Considerable float emery ore has been found on the land of Mr. J. B. Addington, about 2 miles southeast of Fairview and 5 miles south of Franklin, on the Georgia road.

The ore at all these localities is very similar and, like most emery, is an intimate mixture of magnetite and corundum, but the corundum is somewhat coarsely crystallized, so that a rather complete separation can be made by means of the electro-magnet. Preliminary fire tests upon the cleaned product from this ore have shown that it is adapted to use for the manufacture of a vitrified wheel.

While it is probable that there is not an inexhaustible supply of emery at any one of these localities, yet, taken collectively, they represent a source of some importance, which might be considerably increased upon further development. When first prospected their distance from the railroad, 25 miles, prevented their being considered as profitable mining properties; but with the completion of the railroad from Tallulah Falls, Ga., to Franklin, N. C., which is now being built, these deposits will be within 3 miles of a railroad.

SWAIN COUNTY.

There is but one locality in Swain County where corundum is authentically known to occur, and that is about 3 miles a little south of west of Bryson City, on land belonging to Mr. D. W. Kerr, where a splendid quality of blue and pink corundum has been found sparingly in the midst of peridotite (dunite). Little work has been done to determine whether it occurs in commercial quantity; it is not probable that it does.

JACKSON COUNTY.

About three-fourths of a mile 35° east of south of Turkey Knob of Cowee Mountain, on the headwaters of Pumpkintown Creek, corundum has been found sparingly in a greatly decomposed gneissic rock. Considerable prospecting was done here by the National Abrasive Manufacturing Company, but no important corundum deposits were encountered. Near the summit of the Cowee Mountains, about one-fourth of a mile south of Betts Gap, splendid crystals of corundum have been found in the gneiss, associated with small pegmatitic veins. This occurrence was prospected by the Savannah Mining Company of Dillsboro, North Carolina, but no promising deposit was located. Further down the mountain, on Betts Creek, on the farm of Mr. Nelson Jones, corundum associated with garnet is found sparingly in gneiss.

At many points on Caney Fork Creek, a tributary of the Tuckaseegee River, corundum has been found in chlorite schists. Two miles above its mouth, on the McChastain's place, and at Mr. Marion Long's, it is found disseminated through the chlorite-schist in small, rounded nodules, ranging from minute grains to fragments an inch in diameter. A shallow pit was dug that exposed a width of 8 feet of this rock, which was studded with nodules of corundum. It is of the best quality and is well adapted for use in the manufacture of vitrified wheels. These deposits have been worked to some extent by the National Abrasive Manufacturing Company, and in 1901, 20 tons of cleaned corundum were obtained. Half a mile above the junction of Johns Creek with Caney Fork there is a large outcrop of chlorite-schist, having a width of nearly 1,000 feet. As far as is known, no prospecting has been done here, although fragments of corundum have been found on the surface. It has also been found in nodules one-half inch to an inch in diameter in the gneiss, at the mouth of Chastain Creek, 5 miles up Caney Fork, near the residence of Mr. W. W. Brown. Two miles up Chastain Creek corundum has been found in a similar manner in gneiss, near a belt of chloritic rocks.

As far as is known corundum has been found in but one place on the West Fork of the Tuckaseegee River, and that is on Shoal Creek Mountain, 4 miles north of Glenville, where it occurs in a chlorite-schist. In Cashiers Valley, corundum with black spinel is reported to have been found in a peridotite rock near Mr. H. M. Bennett's; also with peridotite on the southern slope of Whiteside Mountain.

The most important corundum localities in this county are in the extreme southeastern portion, in the vicinity of Sapphire, in a section that extends over into Transylvania County, adjoining. In this section there are more than 40 known areas of peridotite, extending across the county in a general northeast and southwest direction for a distance of about 10 miles. All these masses are small, but the location and the relative size of the larger ones are represented on the map, Pl. VII. Corundum has been found associated with many of these, and as indicated on the map, a number have been opened up by a small amount of mining.

Corundum has been mined in this vicinity at several places, known collectively as the Sapphire mines, and owned by the Toxaway Company, of Sapphire. These are located on both sides of Horsepasture River and on the southern and eastern slopes of Great Hogback (Toxaway) Mountain and are described below. The work done at these mines is prospecting rather than systematic mining, but it has shown the existence of considerable quantities of corundum.

Somewhat less than a mile northeast of Sapphire the county road crosses a peridotite formation, associated with which is the Sapphire mine. The little mining that has been done here shows a large quantity of corundum near the contact. According to the former superintendent, the vein has been tested by tunnels and pits for a distance of 300 feet and corundum was encountered in nearly all of them. It is in crystals and masses of a gray and white color, often mottled with blue, is of fine quality, and makes a splendid vitrified wheel.

The Socrates mine is located on a bold outcrop of peridotite about three-fourths of a mile southwest of the Sapphire mine, on the north end of Bear Pen Mountain. Most of the work here has been done on interior veins, but at the top of the hill a border vein was encountered. Sufficient work, however, has not been done to determine the extent of the deposit. The corundum occurs in rough, knotty nodules, which are readily cleaned and which furnish one of the best cutting corundums.

More work has been done at the Bad Creek mine than at any of the other Sapphire mines. It is on the west side of Bear Pen Mountain, about one-half a mile from the Socrates. The mining here has been done almost entirely on a border vein, which has been exposed for a distance of 130 feet and has been worked at one point to a depth of 60 feet.

Two distinct ores have been encountered in this vein; one is a mixture of corundum, garnet, and hornblende; in the other, which is free from garnet, the corundum is associated with apatite in a matrix of biotite-mica (see B, Pl. XXX). These two ores should always be kept separate, for the corundum can be readily cleaned from the associated minerals in the biotite ore, and will yield a product, free from garnet, that can be used in the manufacture of the vitrified wheel; while the corundum in the other ore cannot be entirely separated from the garnet. The vein is nearly 9 feet in average width and carries from 15 to 20 per cent of corundum, some portions being still richer.

Near the southwest end of this series of outcrops of peridotite is the Whitewater mine. It is about 6 miles southwest of Sapphire, on Whitewater River. The work done at this mine consists of a tunnel 160 feet long, which is 40 to 50 feet below the surface. It was started in peridotite, which it penetrated for 110 feet, when gneiss was encountered. At this point the course of the tunnel was turned from southward to eastward, but it is for the most part wholly within the gneiss. An interior vein was encountered from which 30,000 pounds of corundum were obtained. The vein was worked out from the surface to the level of the tunnel. It seems probable that if work were started at the contact of the peridotite and gneiss a border vein of corundum would be found.

The corundum is of good quality and is similar to that at the Sapphire mine.

Besides these, the Sapphire mines also include the Burnt Rock and Brockton mines described under Transylvania County below.

Work was begun in 1892 by the Sapphire Valley Mining Company, at the Burnt Rock mine, and shortly afterward the other mines were opened. A complete crushing and cleaning plant was erected on Horsepasture River and was one of the best mills in the corundum district. The commercial product was hauled to the railroad at Hendersonville, a distance of 50 miles. The Transylvania Railroad has now been built from Hendersonville to Toxaway, a distance of 40 miles. This will shorten the distance of transportation to the railroad to about 19 miles. Work was suspended during 1893 and has not yet been resumed. In 1895 the mines passed into the possession of the Toxaway Company.

Corundum has been found at a number of the peridotite outcrops between the Bad Creek and Whitewater mines, in Jackson and Transylvania counties, as indicated on the map, Plate II. These are on Snake Ridge, which rises from Thompson River valley, in the vicinity of Montvale, many of them being on the land of Dr. C. Grimshawe. This does not by any means indicate that there are large deposits of corundum in these rocks, but when the deposits already found northeast and southwest of these are taken into consideration, it does indicate that there is a possibility that such deposits exist, and it makes the section a promising one for systematic prospecting.

The only one of these localities that is worthy of special mention is the "Gem mine," which is located about one-half a mile south of the Thompson mine, on the Mill Ridge tract. In the gravel deposits of the streams at the foot of the hill in which the peridotite occurs, a number of fair ruby and sapphire gems have been found. A shaft 20 feet deep was sunk on the formation and some gem material was obtained. A large proportion of the corundum found here has been of gem color and quality.

TRANSYLVANIA COUNTY.

Some of the occurrences of corundum in this county have already been mentioned in connection with the Sapphire mines, and these are the Burnt Rock and Brockton localities, on the slopes of Great Hogback (Toxaway) Mountain. The Burnt Rock mine is about 5 miles northeast of Sapphire. All the mining has been done within the peridotite formation and 18,000 to 20,000 pounds of corundum have been taken out. It is of good quality and for the most part is in crystals and knotty nodules, although some masses were found that weighed 25 pounds. The ore is free from garnet and can be easily cleaned. The work done here indicates that there is a considerable quantity of good corundum associated with this peridotite near its contact with the gneiss.

At the Brockton mine, approximately 1 mile south of the Burnt Rock mine, about 72 tons of a dull gray crystal and sand corundum were obtained from two shallow pockets that were entirely within the peridotite formation, but near its contact with the gneiss. No true border vein has been located and it is probable that the corundum found was in interior veins which had extended from a border vein. The corundum is readily separated from the vermiculite gangue and is easily cleaned.

Corundum is also reported to have been found in the enstatite rocks in the same vicinity, on the headwaters of the Toxaway River, at the time the mining was being carried on at these mines.

On the west fork of French Broad River, corundum has been found associated with similar rocks on a hill just west of the mouth of Owens Creek. A number of shallow pits have been dug in prospecting, and large masses of margarite thrown out, some of which carried corundum and black tourmaline.

A large number of similar outcrops are found to the eastward and northwest, and corundum is said to occur with some of these on the North Fork of the French Broad River.

Near the mouth of Owens Creek, east of the locality just mentioned, a number of large boulders of pale-green cyanite have been found on the surface, which contained grains and crystals of deep sapphire-blue corundum. The rocks at this locality are ordinary gneiss.

HAYWOOD COUNTY.

Considerable prospecting for corundum has been done on the land of Mr. J. H. Edmondson, at Retreat, on Pigeon River, 6 miles southeast of Waynesville. For many years corundum has been known to occur in the soil and gravel beds of the streams flowing into Pigeon River from the west, but none was found in place until 1899. During that year the National Abrasive Manufacturing Company prospected rather extensively in the hills above these gravel deposits. The rocks are saprolitic garnetiferous gneisses or schists, cutting through which are many small pegmatitic dikes accompanied by seams of vermiculites, both carrying a small amount of corundum. While the percentage of corundum in the rocks is very low, it is of sufficient quantity to account for the corundum concentrated in the gravels below. Cyanite and garnet are found associated with the corundum.

Three miles northeast of Canton corundum has been found on the surface near an outcrop of peridotite (dunite), but none has yet been discovered in place. A mile north of this is the Presley mine, where corundum of a blue to bluish gray color occurs in pegmatitic dikes cutting through a dark green amphibolite. Considerable work has been done here for corundum, but from what can be seen at the present time, the deposit is not promising. The corundum is found surrounded by both feldspar and mica (muscovite), and in some instances the muscovite has been derived from it. The corundum is of good quality and a preliminary fire test showed that it was adapted to the manufacture of the vitrified wheel. It occurs in rough crystals and fragments, some of which weighed 6 to 10 pounds.

Red corundum has been found on the surface near a small mass of dunite, just south of Newfound Gap. It has been reported to occur near the Gap between Cabes and Crabtree creeks, in connection with an outcrop of soapstone.

BUNCOMBE COUNTY.

Although there are a number of peridotite outcrops in this county, corundum has been found but sparingly associated with them. A very little corundum was obtained at Democrat in prospecting the long strip of peridotite which crosses Ivy River at this place. But little prospecting has been done here and there is nothing that would indicate any considerable quantity of corundum. This is just south of the Carter mine, in Madison County, described below.

On the Elk Mountain range, a few miles north of Asheville, corundum associated with garnet has recently been found by Mr. C. E. Lyman, of Asheville. It is sometimes entirely inclosed by the garnet and at others incloses the garnet. The corundum occurs in a garnetiferous gneiss, near its contact with a pegmatitic dike, and although it is somewhat abundant it is very doubtful whether it will prove to be a commercial source of corundum. It is found in crystals that sometimes measure as much as an inch in diameter. They are prismatic and terminated by the basal plane. They vary considerably in color, from blue to red, and a few gems have been cut from some of the crystals.

The only other known localities of corundum in this county are at Swannanoa Gap, where it has occasionally been found on the surface in masses of cyanite; and 9 miles north of Asheville, near the Swannanoa railroad depot, where it has been found of a blue color in the soil on the north side of the railroad track.

MADISON COUNTY.

It is interesting to note here that the first corundum found in North Carolina—a large mass of dark-blue cleavable corundum—was picked up on the surface in this county in 1847 about 3 miles below Marshall, on French Broad River, just above the mouth of Little Pine Creek. The next year a smaller piece was similarly found (see also page 208). The flat bottom land on which the corundum was found is at the foot of a hill that rises rather abruptly from the south shore of the French Broad River and between Little Bear and Pine creeks. The enclosing country rocks are hornblende-gneisses, and a careful search was made for corundum along the contact of these rocks with the pyroxenite and in the debris broken off from them and deposited in the gullies and branches, but not a trace of corundum was found. A narrow strip of peridotite crosses the river near this point, but as far as is known no corundum has been found in it.

Corundum has been found in large gray crystals on the surface of a large outcrop of amphibolite 3 miles above Marshall and half a mile north of the mouth of Ivy River. Mr. G. C. Haynie, of Marshall, the owner of the property, has in his possession a crystal from this place that weighs 17 pounds (see fig. 24, p. 208).

The Carter mine is in the southeastern corner of the county, very close to the Buncombe County line. It is located on Holcombe Branch, a tributary of Little Ivy River and near the northern end of a strip of dunite which extends from Morgan Hill, in Buncombe County, a distance of more than 2 miles, and which has an average width of about one-fourth of a mile. The corundum that has been mined was found in an interior vein and was enclosed by chlorite and vermiculite. It was obtained in white, pink, and blue masses, which were intimately associated with greenish black spinel and feldspar. While some mining has been done here, the locality has not been thoroughly prospected, and future developments may show the existence of a large deposit of corundum near the contact of the peridotite with the gneiss.

There is no obvious reason why this ore could not be used in the manufacture of any kind of an abrasive wheel. Although the corundum cannot be entirely separated from the spinel, this should not interfere with its use.

Corundum was first found here by Dr. C. D. Smith about 1880 and soon afterwards work was begun by Mr. William Carter and Dr. H. S. Lucas, who took out a few tons in prospecting. Later a little prospecting was done by Mr. M. E. Carter, and by Messrs. Rice and Coleman, who sold the property to Tarr, Hamilton & Company, of New York, who began regular mining about 1886. A steam crushing and cleaning plant was erected at the mine, and about 20 tons of corundum were cleaned and shipped from Marshall. Mining continued only about six months, and has not since been resumed.

Very near the head of a small stream above the Carter mine, a corundum crystal of mottled blue and white corundum weighing 46 pounds was found on the surface by Mr. John A. Carter, of Democrat. It was hexagonal in outline, though rough and partially broken, and has the rhombohedral parting well developed. Further search has thus far failed to discover its origin.

YANCEY COUNTY.

CORUNDUM.

At the larger peridotite outcrops in this county no corundum at all has been found, but instead there is a considerable quantity of chromite (see p. 381). There is but one locality where corundum has been mined, and that is at the Hayes (Egypt) mine, 10 miles west of Burnsville, on the western slopes of Sampson Mountain. Corundum was found here in peridotite and the vein was opened up by a cut and tunnel. While the vein is not far from the contact it is not known definitely whether it is a border vein or not, as the tunnel could not be entered. The corundum is of splendid quality and is usually in distinct crystals, though granular masses are sometimes found. It is white and mottled blue and white in color. At this mine a number of specimens of corundum were found directly surrounded by peridotite (dunite) (see p. 204). There is good reason to believe that there is some quantity of corundum at this locality, but its inaccessibility has been a great drawback to further prospecting. The work that has been done here was by Mr. U. S. Hayes.

Eight miles southeast of Burnsville, on Celo Ridge, near South Toe River, corundum has been found in crystals, 2 to 3 inches in diameter, in the decomposed gneiss adjoining an outcrop of enstatolite (enstatite rock).

EMERY.

The only other locality known in this county where corundum has been found is 6 miles north of Burnsville, on the south side of Mine Fork one-half mile above its mouth and 300 feet above the level of the stream. It occurs here in very finely divided particles in a mixture of magnetite, menaccanite, and staurolite, constituting an emery. The staurolite is transparent and of a rich brownish color and has been mistaken for corundum. An analysis of this staurolite is given on page 304. The staurolite and corundum together constitute from 5 to 10 per cent of these mixed minerals. The only work that has been done here is the sinking of two small openings, 75 feet apart on the strike of the ore, which has exposed the same for a width of 6 to 10 feet. Nearer the summit of the ridge and to the west, a similar outcrop of ore was found. Unless it is proved by further work that the percentage of corundum increases, this deposit will not have any commercial value as an emery. The construction of the railroad which now passes within 4 miles of the deposit warrants its further development.

MITCHELL COUNTY.

There are many outcrops of peridotite and enstantite rocks in this county, some of which are rather extensive, as indicated on the map, (Pl. II, p. 26), and described on page 56. Except at one place no corundum and but little chlorite has been found associated with any of these outcrops. They have been prospected more or less without any positive results, but systematic work may show the presence of either chromite or corundum in quantity at some of these localities. Fragments of corundum have been picked up on the surface and in a dump of an asbestos prospect at a point 1½ miles up White Oak Creek from Bakersville. The rock here is a massive enstatolite (enstatite rock) with radiating borders similar to those found about dunite at many places.

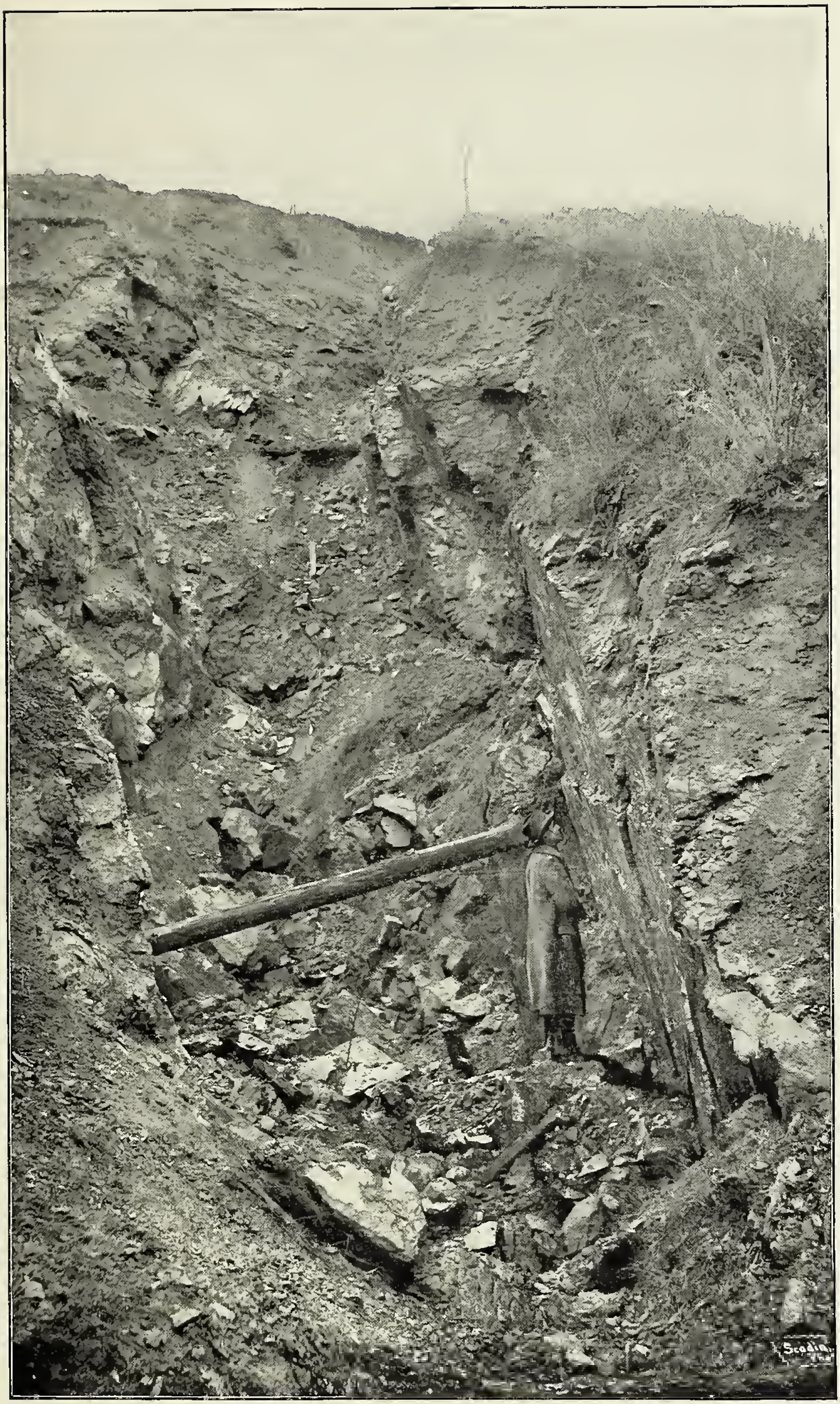
Corundum crystals have been found in the gneiss at Mr. William Bowman's, three-fourths of a mile west of Bakersville.

Mr. D. A. Bowman, of Bakersville, writes that "one mile due east from Bakersville, a massive blue corundum occurs, with now and then a hair-brown piece." He also states that in 1888 he obtained 600 pounds at this place, one piece of which weighed 23½ pounds. It has been reported at various times that sapphire corundum has been found in this vicinity, but no definite information could be obtained of the locality of occurrence. Future developments may show that this county does contain considerable corundum and possibly some that is suitable for cutting into gems.

There is no record that any corundum has been found in the peridotite rocks north of Bakersville.

IREDELL AND ALEXANDER COUNTIES.

In the counties east of the Blue Ridge, all the corundum found has been associated with acidic rocks or amphibolites; none has been found



OPEN CUT ON AN INTERIOR VEIN, MINCEY MINE, MACON COUNTY, N. C.

in peridotites. No large quantity of corundum has been found, though attempts have been made to mine it at a number of places. Most of the occurrences have been thus far only of mineralogical interest and but little economic importance has been attached to them.

Corundum has been found on the surface at a large number of localities in these counties, especially in Iredell, those in Alexander being near the county line. The country rock in this section is a gneiss, but no corundum has yet been found in it. The corundum occurs in grayish masses up to several inches in diameter and in small, rough crystals. These are all more or less altered and usually are encased either in compact muscovite (variety damourite) or margarite. Sometimes there is but a small nucleus of corundum, and the outer mineral has very much the appearance of having been derived from the corundum. Surface specimens of this type have been found at Belts Bridge, Locks Bridge, and at many places between the latter and Liberty Hill, for the most part on the south side of the South Yadkin River. In fig. 27 is represented one of the tapering corundum crystals enclosed by margarite. The analysis of the margarite is given on page 315. Crystalline masses of grayish white corundum associated with muscovite and black tourmaline have also been found here.

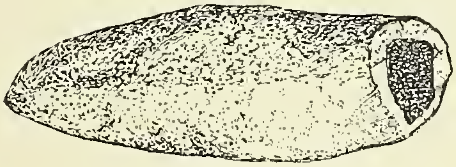


FIG. 27.—Corundum crystals enclosed by margarite; from Belts Bridge, Iredell County, N. C.

Corundum was first found in Iredell County about 1875, when a specimen was picked up near the site of the Acme mine, which is located about three-fourths of a mile west of Statesville, and half a mile south of the Charlotte and Taylorsville Railroad. The mine was operated by the Acme Corundum and Mining Company under the management of Mr. H. A. Collins, and it is sometimes called the Collins mine.

The first work done here by the company was in the alluvial deposits of clay and gravel, which were about 15 feet deep. The mine was situated in a depression near the head of a small stream, and considerable difficulty was experienced in preventing masses of the clay and gravel from slipping back into the workings, as the deposits were thoroughly saturated with water. After the clays and gravels had been passed through, an amphibolite rock was encountered, which contained a vein of feldspar and vermiculite that carried corundum. In its widest place this vein was 2½ feet thick. While the corundum is sometimes found with the feldspar, most of it has been thus far found with the vermiculites. It is in distinct crystals and round clusters of crystals, of gray, pink, blue, and white colors. Sometimes margarite accompanies it, and sometimes cyanite, and masses of one and the other of these with corundum have been found on the surface.

Mining was begun here in 1893 and continued about one year. A steam crushing and cleaning plant was erected and about 50 tons of commercial corundum were obtained. Mining was resumed for a short time the latter part of 1894, but it was more in the nature of prospecting, and since then no work has been done.

The only other locality where corundum has been found in place in this region is 8 miles northwest of Statesville, just north of the Charlotte and Taylorsville Railroad, near Amity Church, at the Hunter place. The occurrence here is very similar to that at the Acme mine, except that no deep alluvial deposit was encountered and the amphibolite is of somewhat finer texture. The corundum is associated with feldspar and vermiculites, and is of an almost coal-black color. Large masses of corundum with margarite have been found on the surface near this place.

On account of the depth of soil and decomposed rock but little is known of the extent of the corundum veins or of the amphibolites. The mode of occurrence at both these places is described and figured on page 209 (fig. 25).

BURKE, CLEVELAND, AND MCDOWELL COUNTIES.

Near the borders of Burke and Cleveland counties, at the corner of Catawba, corundum in grayish blue tapering crystals has been found on the surface, along the ridge leading northwest of Carpenters knob. In the watershed of the South Fork of Catawba River, in Burke County, corundum of a similar nature has been found in pockets containing from 100 to 200 pounds. The rocks in this region are highly garnetiferous gneisses and schists. The probability of the occurrence of corundum in quantity in this region is very small and not sufficient to stimulate any systematic prospecting. In many of the gravel deposits of Burke, Cleveland and McDowell counties that have been worked for gold and monazite, small grains and crystals of corundum have been found. Dr. Genth has reported the occurrence of massive grayish-white corundum at Brackettstown in McDowell County.

GASTON COUNTY.

Dr. C. L. Hunter first discovered corundum in this county at Crowders and afterwards at Chubbs and Kings mountains in reddish and bluish masses that were sometimes crystallized. It was reported to occur in place, associated with mica and quartz. That at Crowders Mountain is in places associated with iron oxide, and there is a transition to a granular emery. No quantity of corundum has been found here and the occurrence has been of mineralogical interest only. Prof. Richard T. Brumby, of the College of South Carolina, also collected specimens of corundum from Chubb Mountain in 1852. These specimens are now in the college mineral collection with Professor Brumby's original labels.

GUILFORD COUNTY.

The only occurrence of corundum known in this county is in connection with the titaniferous iron ore belt that traverses the northwest corner of the county. Dr. Genth[15] made a chemical and mineralogical examination of these ores and in a report on them says: "All the ores consist of mixtures of magnetic iron with titaniferous hematite, or menaccanite, or probably also with rutile (titanic acid), mixed with a chloritic mineral, or a silvery micaceous one resulting from its decomposition. Some of the ores contain alumina in the form of granular corundum, in one or two places in such quantities that they become true emery ores."

These were found about 7 miles northeast of Friendship, on what is supposed was the McCarvisten (or McCuistian) place. Two varieties are described by Dr. Genth, one a reddish granular kind, which had "much the appearance of a granular reddish-brown garnet, for which it has been mistaken; but the analysis proved it to be not a silicate mixed with granular magnetite, but corundum." The other was grayish in color and "the minute grains of corundum have a yellowish or brownish yellow color, and show in many places cleavage fractures, which give it the appearance of a feldspathic mineral." These two emery ores have been analyzed by Dr. Genth[16] with the following results:

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[15] Geol. Survey of North Carolina, Vol. II, Part II, 1893, p. 148.

[16] Loc. cit., p. 150.

Analyses of emery ores from Guilford County.

	Reddish Brown.	Gray.
SiO_2	1.39	0.98
TiO_2	0.78	2.42
Fe_3O_4	42.77	46.29
MnO and CaO	1.00	1.27
Cr_2O_3	0.30	Trace.
Al_2O_3	52.24	44.86
MgO	0.68	3.27
CaO	0.84	0.91

If these should be found in quantity, they would be of considerable value as a source of emery. The amount that was found was small and at that time did not stimulate any special prospecting for a large deposit. The exact place where this emery was found is not now known—only the general location, as given above.

NORTH CAROLINA, OTHER LOCALITIES.

In the report of the North Carolina Geological Survey for 1875, large hexagonal crystals of corundum are reported from Forsyth County (page 299), and a reddish variety from Polk County (Appendix, page 65). Small particles are also said to occur in cyanite in Wilkes County, and Dr. Genth says that " rarely small remnants of corundum are found in the pyrophyllite slates of Chatham County." He also reports the occurrence of the emery variety of corundum near Winston-Salem, associated with titaniferous iron ores, and it is probably similar to what he has described from Guilford County. Most of the occurrences just mentioned are of specimens picked up on the surface and, on account of the locality in which they have been found, have had but little importance attached to them.

FOREIGN CORUNDUM AND EMERY DEPOSITS.

Until within the last few years there were no localities outside of the United States where corundum was mined for abrasive purposes, with the exception of the emery deposits of Turkey and of the Grecian Archipelago. This condition is now changed, for corundum has been mined in India and exported to the United States and to Europe; and during 1901 the Canadian deposits became producers and shipped their product principally to Europe and the United States.

CORUNDUM.

Canada.—The Canadian corundum deposits, which have been attracting considerable attention, are in the Province of Ontario. The corundum occurs as a primary constituent of syenite and of nepheline-syenite, which have been traced for over 50 miles across Renfrew, Hastings, and Haliburton counties, smaller belts of the same rock occurring in Peterborough, Lanark, and Frontenac counties to the south, making a total distance of nearly 100 miles in which these rocks have been found.

The rock varies from normal syenite to nepheline-syenite and mica-syenite. Corundum has been found in all three of these varieties, but it is most abundant in the normal syenite. These rocks, which often occur as dikes cutting the gneisses, are sometimes in large masses that appear to grade into granite. The dikes vary greatly in width, being usually several feet wide, but some have been observed that were only a few inches wide and these were thickly studded with corundum crystals. Analyses of specimens of this rock taken from various parts of the field show that it contains from 5 to 15 per cent of corundum.

The principal operator of these corundum deposits is the Canada Corundum Company, Limited, which owns deposits in the townships of Raglan, Radcliffe, Brudenell, Carlow, Monteagle, and Dungannon. This company's principal works are located in the extreme northwestern part of Raglan Township, Renfrew County, about 7 miles southwest of Combermere, where a corundum mill having a capacity of 5 tons of cleaned corundum a day has been erected. The percentage of corundum in the commercial product is higher than in any that has been on the market for a good many years. When this corundum was discovered in the normal syenite, its surface showed a superficial alteration which partially or wholly destroyed its abrasive value. As mining was carried deeper, however, this alteration was found to grow less and finally to disappear, so that the more recent tests of corundum shipped from this mine show that it is a very pure commercial corundum that gives good satisfaction as an abrasive. One of the chief difficulties encountered in cleaning this corundum was the elimination of the feldspar, but this has finally been overcome.

Specimens of corundum that are entirely enclosed by mica have been found in Methuen Township, Peterborough County. Prof. W. G. Miller[17] has described these as follows: "The corundum is often not observable in the mica until the latter is broken open, when it is found forming the center or core of the mass. The rounded surfaces of the corundum and other characteristics leads to the belief that the masses of light-colored mica are secondary products after corundum." This resembles very closely specimens of corundum surrounded by muscovite mica that have been found at the Presley mine in Haywood County, North Carolina (see page 257), in which the muscovite is undoubtedly a secondary product after corundum.

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[17] Rept. Bureau of Mines, Toronto, Ontario, VIII, Part 2, 1899, p. 10.

In the township of South Sherbrook, Lanark County, corundum has been found in a rock that is made up of a basic plagioclase feldspar and green hornblende, and that has been called anorthosite by Professor Miller. It is more basic in character than the typical varieties of this rock that have been described from other parts of Canada. The width of this belt of rock is nearly ¾ mile and the corundum is found throughout the whole distance. It occurs in crystals of an almost uniform light gray to white color, that are usually about ½ inch in diameter, the largest ones being 1¼ inches long.

India.—The corundum deposits of India have been described by T. H. Holland,[18] who states that the Pararapatti area, in the Salem district of the province of Upper Burma is one of the most promising localities for the mining of corundum for abrasive purposes. The corundum occurs in a matrix of deep flesh-colored feldspar which is in bands of lenticular masses and has often associated with it a considerable proportion of sillimanite, rutile, opaque black and green spinel, and biotite. These masses are sometimes as large as 15 feet long and 8 feet in diameter where they have been actually seen in the rock. The feldspar rock is composed essentially of anorthite and hornblende, and the parts that carry the corundum have a gneissoid structure. The corundum varies from a deep purplish brown to a dark greenish gray and is in irregular lumps varying from a quarter of an inch to an inch in diameter, and in elongated barrel-shaped crystals up to one inch long.

There are two and perhaps more of these corundum-bearing bands, lying parallel to each other, the total length of corundum-bearing rock extending for about 24 miles. The percentage of corundum in the rock is very low, experiments that have been made at different points on the band, showing the presence of only 3.5 per cent.

In close proximity to some of these corundum bands are nepheline-syenite, but no corundum has been found in it. Most of the outcrops of the corundum rock have been found in connection with gneiss, and lie in successive lines that are roughly parallel to the strike of the gneiss.

Specimens of corundum received through Dr. T. L. Walker from this general vicinity and labelled, "Pipra, South Revah, India," are apparently similar to those described by Mr. Holland. The corundum, which is very fine grained in appearance, occurs in nodules up to two or more inches long by one or more inches broad, with a pinkish to purplish brown color. These nodules are partially or completely surrounded by a greenish mica, having small and rather brittle folia, which has been referred by Professor Mallet to the euphyllite variety. In the mica there are small, rough crystals of tourmaline. The mode of occurrence of this corundum ore is not known, but its general appearance indicates that it is an ore from which the corundum could be readily separated so as to afford a very clean product. If the corundum in the rock is 10 per cent or more of the amount required to be removed in mining, this should make a very important and profitable deposit.

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[18] Geol. Survey India, Economic Geology, Part I, 1898, Corundum.

In another specimen, labelled " Salbanni, 4 miles E. SE. of Barampur, Manbhoorn district, India," there are blue crystals of corundum with a rough hexagonal prism imbedded in a mass of interlocking bladed crystals of cyanite. These are not so promising as the others as a corundum ore.

It is very probable that nearly all the corundum deposits that are known in India are secondary minerals that are the results of metamorphism. Professor Judd, in his paper on the Rubies of Burma and associated Minerals, says that all the corundum-bearing rocks in the districts of Southern Asia appear to be gneisses that are sometimes passing into schists and that frequently contain masses of limestone and dolomite.

EMERY.

Turkey.[19]—Prior to 1846 emery, although known to exist in greater or less abundance in other places, was supplied to the arts almost entirely from the island of Naxos in the Grecian archipelago. In the latter part of that year Dr. J. Lawrence Smith, in the employ of the Turkish government, made a trip to different parts of Asia Minor where it was reported that emery had been found. As a result of his visit and of his examination of these localities new deposits of emery were discovered and mines were opened that soon became the competitors of the Naxos mines and caused a great reduction in the price of the ore. The first locality that Dr. Smith examined was Gumuch-dagh, a mountain about 12 miles east of the ruins of Ephesus. The port for this locality is Smyrna; between Smyrna and Gumuch-dagh emery is found in a valley about 20 miles south of Smyrna, called Allahinan-Bourgs. At the foot of the mountain is the village Gumach.

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[19] J. Lawrence Smith, Emery formation of Asia Minor; Am. Jour. Sci., 2d. ser., Vol. VII, 1849, p. 283; Vol. IX, 1850, p. 289; Vol. X, 1850, p. 354; Vol. XI, 1851, p. 53; and Scientific Researches, 1851, pp. 1-53. Thomae, W. F. A., Trans. Am. Inst. Min. Eng., Vol. XXVIII, 1898, p. 208. Stevens, W. E., U. S. Consular Reports, No. 55, Aug. 1885.

The emery as it occurs in this locality is imbedded in a bluish coarse-grained marble, resting upon mica-slates, schists, and gneisses. The emery was found in the greatest abundance about 3 miles from the village of Gumach, near the summit of the mountain and about 1800 feet above the level of the valley. A great deal of emery was scattered on the surface varying in size from small particles to masses several tons in weight.

According to Dr. Smith's[20] description, the emery does not occur in a vein but is irregularly scattered through the rock or occurs in small to large pockets or masses. At times it forms an almost solid mass several yards in length and breadth.

The locality, second in importance, that Dr. Smith discovered is known as the Kulah district. It is near the town of Kulah, which is about 150 miles from the village of Gumach and about 20 miles from the ancient city of Philadelphia.

The emery occurs here in a manner similar to that at Gumuch-dagh, in a white, granular to compact limestone resting on mica-slate, hornblende-schist, gneiss and granite. None of these rocks, although all were carefully examined by Dr. Smith, showed the slightest trace of corundum. The emery is not so abundant here as at the first locality, and a few years after mining was commenced this locality was abandoned for those nearer the sea.

Emery was also found in small quantities near Adula, a town about 12 or 15 miles east of Kulah, and also at Manser, about 24 miles north of Smyrna. In both these places the emery is associated with granular limestone.

Grecian Archipelago.—In a number of the islands of the Grecian Archipelago emery has been found in considerable quantities. The most important of these localities is the island of Naxos, where emery is found in large blocks more or less mixed with the red soil and also imbedded in a white marble.

The deposits are located principally on the north and east sides of the island, the best ore coming from Vothrie, which is 9 miles from the coast. Another one of the better localities on the island is Apperonthos, which is 7 miles from the coast. In the southern part of the island the emery is found near Yasso. The emery has been found in such abundance on the island in loose boulders and in the soil that it has been necessary to do but little work quarrying for it in the rock.

On the island of Nicaria emery is found equal in quality to the Naxos emery, but the quantity is not so great. The mode of occurrence is the same as at the other localities, and when found in place the emery is always in contact with the limestone. On the island of Samos there has been found, imbedded in the soil, a small amount of emery, to which was attached a little calcareous rock.

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[20] See references on p. 267.

These emeries vary considerably in appearance. The Gumuch-dagh is usually in fine grains, is dark-blue to purplish in color, and is similar to some varieties of magnetite. The interior of the masses of this emery is usually free from the micaceous inclusions that are common to many of the emeries. The Kulah emery is coarser grained and much darker in color than the Gumuch-dagh, and its external surface sometimes resembles that of the mineral chromite. The Naxos emery is dark gray in color, mottled by small particles of a micaceous mineral that are disseminated through it. It often contains bluish particles of corundum that are readily recognized. Some of the emery from the island of Nicaria presents a schistose or lamellated structure, many specimens resembling certain gneisses. Its color is dark blue and it is sometimes mottled like the Naxos emery. A compact variety is also found at this locality. There is in the schistose variety a considerable amount of micaceous mineral which undoubtedly determines its structure. The emery from the island of Samos is of a uniformly dark-blue color and is both coarse and fine-grained.

The emery is mined in the simplest way and owing to its great abundance in the soil and as loose boulders on the surface of the ground, it was many years before much exploration in the rocks themselves was necessary.

Blocks of ore when not too large are transported in their natural condition to the coast, but frequently they have to be broken, and when too large to break with hammers they are heated for several hours and on cooling they usually yield to the blows of a hammer. Another method of breaking these large blocks is to suddenly cool them with water after heating.

The shipping point of the emery from all these localities is Smyrna, and as it is usually taken as ballast the cost of transportation is very low; the actual cost of the emery laid down on the docks in a foreign port is about one cent a pound. Thus it can be seen that if this mineral from these foreign localities should be brought in free of duty it would make close competition for the emery mines in this country.

CHAPTER IX.

THE ALTERATION OF CORUNDUM AND ITS ASSOCIATED MINERALS.

The alterations observed in corundum deposits have been brought about by the same agencies that are described in connection with the decomposition of the peridotites in Chapter IV. It is in the contact zone that alteration and decomposition take place most readily and rapidly; but on account of the joints and seams in peridotites, the interior veins are also subject to rapid decomposition.

As the waters containing the various chemical reagents in solution percolate downward through the deposits, they act upon the corundum and other primary minerals, causing the formation of a large number of alteration products. Thus the upper portion of the corundum vein or deposit is very different in mineralogical and physical characteristics from that at greater depths, where these surface influences have been unable to act.

Corundum is a mineral which at the earth's surface is one of the most unalterable of substances, as is well exemplified by the fragments that are found in the soil and in the stream gravels, which show no sign of chemical alteration on their surfaces. But, on the other hand, conditions have existed beneath the surface that have brought about an extensive alteration in the corundum, as shown by the occurrence of many undoubted pseudomorphs after this mineral. There are also many alteration products found in these deposits, in the formation of which corundum has played an important part, but true pseudomorphs have not been produced. These are well illustrated in the zones of alteration products developed in corundum veins in peridotite.

There have been but few investigations in this field and hence our knowledge of the relations of the associated minerals to the corundum is very limited. The most extensive work along this line has been done by Dr. J. Lawrence Smith and Dr. F. A. Genth, and in the descriptions of the associated minerals which follow material has been freely drawn from the publications of both. There is a great diversity in the minerals associated with corundum, corresponding chiefly to the several modes of occurrence; but there are also notable differences of association between different localities where the mode of occurrence is the same. Where the corundum occurs in gneiss and granite there are but few associated minerals and the corundum has suffered but little alteration. On the other hand, where it is found in the peridotites there are a great variety of associated minerals and the corundum has suffered very extensive alteration. The determination of the origin of the corundum throws considerable light on its relation to the associated minerals. Most of these are the result of reactions between the corundum and the enclosing rock and the direct alteration of the corundum due to percolating waters, but some are primary minerals—that is, they were formed at the same time as the corundum and are not the result of alteration.

As most of the corundum in North Carolina is found in peridotites, a knowledge of the minerals associated with it in this occurrence will be of special interest and aid to the miner and prospector. These usually include some species of the chlorite and vermiculite groups and a series of other aluminous and magnesian minerals. While the various occurrences of corundum in the peridotites show a considerable difference, at times, in the species of the associated minerals, they all agree in containing chiefly magnesian minerals and in the absence of any considerable quantity of quartz and mica of the muscovite group.

The associated minerals can readily be divided into five groups: (1) Those that were formed at the same time as the corundum, as chromite and the mineral constituents of the rocks; (2) those that have been formed by the direct reaction of the corundum with the enclosing rocks and by hydration, as diaspore, muscovite, and chlorite; (3) those that are the result of the alteration of primary minerals; (4) those that are the result of the decomposition of some of the secondary minerals, as the vermiculites; and (5) those that have been formed by the addition of some external elements, as apatite, dolomite, and chalcopyrite.

Where corundum occurs in peridotite, the associated minerals containing magnesia are much more abundant than those containing alumina, there being a much broader and more varied series of minerals between the unaltered peridotite and the alumina-magnesia zone of minerals than between this zone and the corundum. This phenomenon is well represented on a small scale by the corrosion mantles described on pages 79 and 146 and figured in Pl. XXXVIII.

Corundophilite, which is so commonly observed at the corundum and emery localities of Asia Minor and at Chester, Mass., has not been identified in North Carolina, but clinochlore is the common chlorite here associated with the corundum. Again, zoisite is very common at some of the localities in this State, while epidote is almost entirely wanting.

Diaspore, the hydrous oxide of aluminum, commonly associated with corundum, has been identified at but one locality in this State, the Corundum Hill mine, from which one specimen has been reported.

In the following pages descriptions are given of all minerals that have been described as occurring with corundum. Those that have been found in this State are described first and the others are given as an appendix to the list.

The associated minerals are here described in the order in which they are arranged in Dana's Mineralogy, where the minerals are classified in groups according to their chemical and physical properties.

An alphabetical list of the minerals that have been found associated with corundum in North Carolina is given below. The number before each mineral name corresponds to that under which it is described in the text.

List of minerals found associated with corundum.

26b. Actinolite.
17. Albite.
29. Almandite.
26. Amphibole.
19. Andesine.
30. Andradite.
21. Anorthite.
25. Anthophyllite.
61. Apatite.
27. Arfvedsonite.
16. Aragonite.
26d. Asbestos (an amphibole).
42. Biotite.
15a. Breunnerite (var. magnesite).
22a. Bronzite (var. enstatite).
54. Cerolite.
40. Chabazite.
4a. Chalcedony (var. quartz).
2. Chalcopyrite.
45-46. Chlorite.
44. Chloritoid.
11. Chromite.
31. Chrysolite (or olivine).
53c. Chrysotile (var. serpentine).
46. Clinochlore.
47. Culsageeite (var. jefferisite).
34. Cyanite.
26f. Cummingtonite.
41a. Damourite (var. muscovite).
55. Deweylite.
24b. Diallage (a pyroxene).
13. Diaspore.
24a. Diopside (a pyroxene).
34. Disthene (or cyanite).
52. Dudleyite.
26c. Edenite (an amphibole).
22. Enstatite.
36. Epidote.
17-21. Feldspar.
33. Fibrolite (or sillimanite).
41b. Fuchsite (var. muscovite).
9. Gahnite.
28-30. Garnet.
55a. Garnierite (var. genthite).
56. Genthite.
1. Graphite.
54. Gymnite (same as deweylite).
6. Hematite.
26e. Hornblende (an amphibole).
5. Hyalite (var. opal).
23. Hypersthene.
7. Ilmenite (or menaccanite).
47. Jefferisite.
46b. Kammererite (var. pennite).
59. Kaolinite.
59. Kaolin (or kaolinite).
48. Kerrite.
9. Kreittonite.
20. Labradorite.
62. Lazulite.

List of minerals found associated with corundum.—Continued.

14. Limonite.
50. Lucasite.
49. Maconite.
15. Magnesite.
10. Magnetite.
43. Margarite.
53b. Marmolite (var. serpentine).
58. Meerschaum (or sepiolite).
32. Meionite.
7. Menaccanite (or ilmenite).
11a. Mitchellite (var. chromite).
41. Muscovite.
18. Oligoclase.
31. Olivine (or chrysolite).
5. Opal (hyalite).
62. Paranthite (or meionite).
26e. Pargasite (var. hornblende).
46a. Penninite.
8a. Picotite (var. spinel).
53d. Picrolite (var. serpentine).
45. Prochlorite.
3. Pyrite.
60. Pyrophyllite.
24. Pyroxene.
4. Quartz.
28. Rhodolite.
45. Ripidolite (see clinochlore).
12. Rutile.
53. Serpentine.
58. Sepiolite.
33. Sillimanite (or fibrolite).
57a. Soapstone (var. talc).
8. Spinel.
38. Staurolite.
57a. Steatite (var. talc).
57. Talc.
37. Tourmaline.
26a. Tremolite.
47-52. Vermiculite.
31a. Villarsite.
39. Wellsite.
51. Willcoxite.
53a. Williamsite (var. serpentine).
35. Zoisite.

NATIVE ELEMENTS.[1]

The native elements are rarely found as associated minerals of corundum, and the only one that has been observed in situ is graphite. When found in gravel deposits, gold is often an associated mineral, but no authenticated record is known of gold having been found in the same rock with corundum, although it has been found in rocks close by.

1. Graphite.

This mineral crystallizes in the hexagonal system, but the crystals are usually roughly developed and are seldom well formed. The hardness of the mineral is but 1, so that it is readily scratched with the fingernail. In color it is bluish to steel gray, black, and has a black streak. On account of its softness, it readily soils the fingers and will leave a mark on paper.

Chemically graphite is carbon, it being thus of the same composition as the diamond. In appearance it resembles very closely the mineral molybdenite, which is a molybdenum sulphide (MoS), from which it can readily be distinguished by heating before the blow-pipe, the molybdenite giving off its sulphur as sulphur dioxide while there is no change in the graphite.

This mineral has been found at the Sheffield mine, Macon County, where it occurs as small flakes on the gneissic rock, in which the corundum is found, also directly with corundum at the Bad Creek mine, Jackson County, and with rubies at Caler Fork of Cowee Creek, Macon County.

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[1] In the descriptions of minerals, the general characteristics are given in smaller type, while the text referring directly to minerals found in North Carolina is given in larger type.

SULPHIDES.

But few sulphides have been found directly associated with corundum—that is, occurring in the same vein or rock with it. They are for the most part found in the gravel deposits from which this mineral has been obtained.

2. Chalcopyrite.

Crystallizing in the sphenoidal group of the tetragonal system, the crystals of chalcopyrite are usually wedge-shaped or in sphenoids; but the mineral is more commonly found massive. The hardness is 3.5 to 4 (see Pyrite, below) and the specific gravity is 4.1 to 4.3. The color is brass yellow, but as the mineral easily tarnishes, it is often variegated in color. On a fresh fracture it has a bright, metallic luster. The composition of this mineral is a copper iron sulphide represented by the formula $CuFeS_2$.

It has been found at but few of the corundum localities and usually as small particles or fragments scattered sparingly through the gneissic rock, rarely as small thin flakes or scales on the corundum. It has been found sparingly at the Sheffield and Bad Creek mines.

3. Pyrite.

This mineral crystallizes in the pyritohedral group of the isometric system. The more common forms of the crystal are the cube, *a* (100), the pyritohedron, or pentagonal dodecahedron, *e* (210), and a combination of these two. The faces of the crystal are often striated parallel to the edge $a \wedge e$ and are sometimes rounded. The hardness is from 6 to 6.5, and by this property it is readily distinguished from chalcopyrite, which is readily scratched by steel. Its specific gravity is 4.95 to 5.10. The color, which is nearly uniform, is very pale brass-yellow, and the luster is bright metallic. Chemically, pyrite is an iron disulphide, having the formula FeS_2.

Pyrite has been observed in small particles and crystals in the midst of fragments of corundum from the Bad Creek mine, at Sapphire, Jackson County. This is the only peridotite corundum vein in which pyrite has been found. It has, however, been observed at many of the corundum occurrences in gneiss.

OTHER SULPHIDES.

In the gravel deposits of Caler Fork of Cowee Creek, Macon County, in which the rubies, described on page 181 occur, there have also been found sperrylite ($PtAs_2$) the rare platinum arsenide which was found very sparingly in minute octahedral crystals up to one that measured 0.4 mm.

in diameter; pyrrhotite, Fe_nS_{n+1}, an iron sulphide similar to pyrite; and sphalerite, ZnS, a zinc sulphide which occurs in small rough fragments, and nodules. None of these has been found in place with corundum. It is not improbable that one or more of these minerals (see also p. 183) will be found associated with the rubies of this region when their origin has been discovered.

OXIDES.

4. Quartz.

Quartz, the oxide of silicon (SiO_2), is not a common associate of corundum, except, of course, in its occurrence in a gneiss, granite, or allied rock, where the quartz is a constituent of the rock itself. Vitreous or glassy quartz has been found in most of the gravel deposits in pebbles and occasional crystals. Crystalline quartz is readily identified by means of the sharp conchoidal or shell-shaped fracture it exhibits when broken, and by its hardness, which is 7, it readily scratching glass.

4a. Chalcedony.—This variety of quartz has nearly the luster of wax and varies from translucent to nearly transparent. The color varies from white to brownish and some specimens were obtained that were of a delicate green color, due probably to the presence of traces of nickel. In form it is mammillary and botryoidal, occurring often in seams and cracks in the rocks.

As an associate of corundum it is found deposited in irregular masses in the joints and cracks of the rocks, as a result of the final weathering and disintegration of the peridotites. It has been found at nearly all of the corundum deposits in these rocks.

5. Opal (var. Hyalite).

This is an amorphous variety of silica containing a varying amount of water and having the general formula $SiO_2 . nH_2O$. Its hardness is lower than quartz and varies from 5.5 to 6.5 with the different forms.

The only variety of opal that has been found in connection with the corundum is hyalite, which occurs in perfectly clear and colorless to translucent and whitish globular concretions, and also as crusts with a reniform or botryoidal surface. At the Corundum Hill mine, hyalite in beautiful colorless to white botryoidal incrustations, having very much the appearance of a mass of dew drops have been found upon chlorite. Dr. Genth[2] has also described it as occurring upon corundum, at this locality. It occurs very sparingly here and more rarely at the Carter mine, in Madison County. Near Elf, Clay County, hyalite also occurs in clear drop-like masses and thin incrustations in some of the limonite geodes, resulting from the decomposition of the peridotite.

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[2] Proc. Am. Phil. Soc., Vol. XIII, 1873, p. 371.

6. *Hematite.*

Hematite crystallizes in the rhombohedral division of the hexagonal system, and its crystals are similar to those of corundum, as are also many of its physical and chemical properties. It is from 5.5 to 6.5 in hardness. It can readily be distinguished from the other iron oxides by its red or reddish brown streak and its being anhydrous. Its composition is represented by the formula Fe_2O_3.

This mineral, which is also known as specular iron ore, is sometimes found as a constituent of emery. It has also been found sparingly at a number of corundum localities in the amorphous forms, as a result of the alteration of the dunite.

7. *Ilmenite or Menaccanite.*

Ilmenite crystallizes in the rhombohedron division of the hexagonal system, but it is more often massive and is sometimes in thin plates. It is an iron-black mineral with a black streak and closely resembles magnetite. It is usually non-magnetic, but is sometimes slightly magnetic. Chemically, ilmenite is a double oxide of iron and titanium, represented by the formula $FeTiO_3$ or $FeO . TiO_2$.

This mineral has been found at but few of the corundum localities. At the Carter mine, in Madison County, it is associated with oligoclase, filling small cross fissures in the corundum vein. The ilmenite is in small masses having indistinct crystalline structure and also in irregular shaped nodules, 1½ to 2 inches in diameter. These two varieties have been analyzed by Mr. H. F. Keller[3] with the following results:

Analyses of two varieties of ilmenite from Carter mine, Madison County.

	I.	II.
TiO_2	52.73	52.64
Fe_2O_3	8.08	10.07
FeO	33.08	31.11
MgO	5.33	5.33
SiO_2	0.14	....
	99.36	99.15
Specific gravity	4.67	4.68

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[3] Bull. U. S. Geol. Survey No. 74, p. 32.

Another form of occurrence of this mineral associated with corundum that is very interesting is as minute inclusions in some of the rubies that are found in the gravels of Cowee Creek, Macon County (see page 183).

SPINEL GROUP (8-11).

The minerals of this group (spinel, picotite, gahnite, magnetitc, and chromite) are characterized by their isometric crystallization, the octahedron being thc common form of the crystals, and by their chemical composition, all having the general formula, $RO.R_2O_3$, or $R''R'''_2O_4$.

8. Spinel.

Spinel crystallizes in the isometric system, the octahedron being the more common form of the crystals. Its hardness is 8, or as great as that of topaz, and its specific gravity is from 3.5 to 4. The common colors are various shades of red and blue, green and black. The typical composition of the spinel is $MgAl_2O_4$, but the different varieties vary widely from this. The two common varieties found associated with the corundum are ceylonite or pleonaste (iron-magnesia spinel) and picotite (chrome spinel).

As has been observed, the spinel in North Carolina is generally massive and coarse to fine granular, but is occasionally in crystals. At the Corundum Hill mine massive spinel is found, throughout which are scattered grains and fragments of corundum. At the main shaft of this mine spinel has been found surrounded by radiating chlorite, see A of Pl. XXIX. In the mass it appears black, but in thin splinters the color is green. Dr. Genth[4] has described a crystallized spinel from the same mine. The fine grained variety (a) has been analyzed by Mr. G. A. Koenig[5] and the coarse grained (b) by Dr. Genth.[6] The analyses are given below after deducting mechanical admixtures:

Analyses of spinel from Corundum Hill mine, Macon County.

	a.	b.
Al_2O_3	54.32	66.63
Cr_2O_3	3.96	Trace.
Fe_2O_3	11.51	1.80
FeO	11.16	11.35
MgO	19.05	19.86
CuO	....	0.11
NiO	....	0.25
	100.00	100.00

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[4] Proc. Am. Phil. Soc., Vol. XIII, 1873, p. 368.

[5] Ibid., p. 369.

[6] Ibid., p. 369.

The first analysis shows that the spinel examined was the picotite variety and the second indicates pleonaste.

At the Carter mine, near Democrat, Buncombe County, a massive spinel of a greenish black color is found intergrown with pink and white corundum. In thin splinters, it is of a very handsome emerald green color. These spinels are primary minerals which are formed at the same time as the corundum.

From the Buck Creek mine one specimen of spinel has been reported which consisted of black grains and crystals scattered through a dark-green foliated chlorite.

8a. Picotite.

The chrome spinel, picotite, has been identified at many of the corundum localities, but is usually in minute grains. In the corundum bearing amphibolite rocks from Clay County (p. 82) microscopic grains of picotite are always present, and the smaller grains of corundum are usually intergrown with irregular masses of this mineral and enclose many minute particles of it.

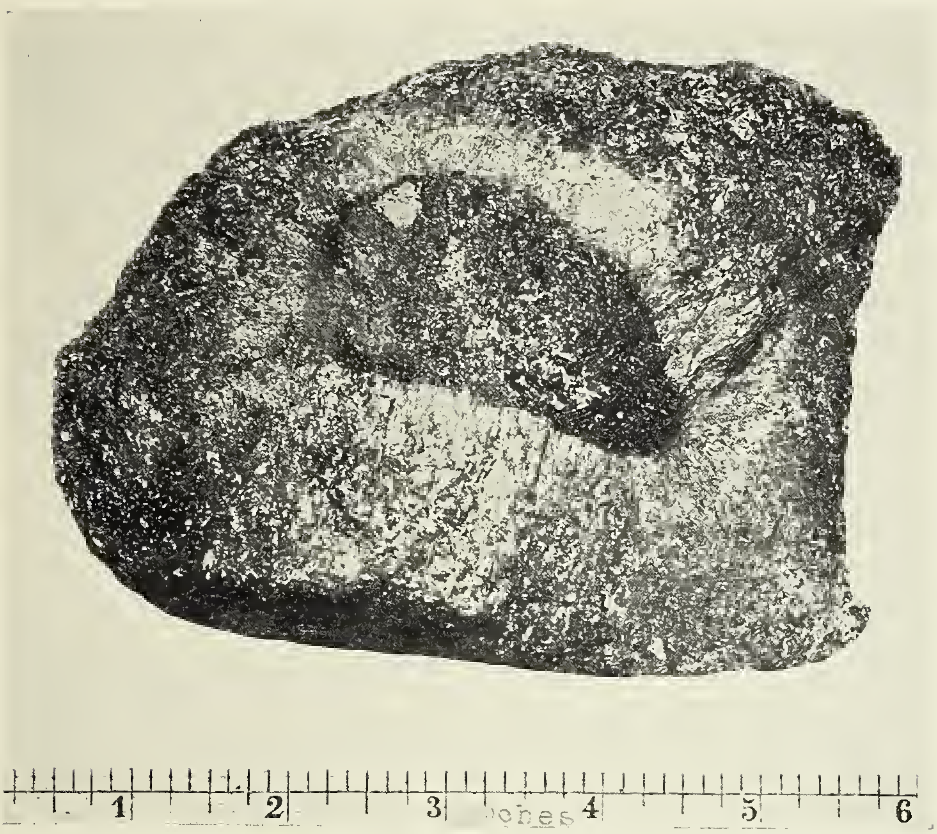
9. Gahnite.

Gahnite or zinc spinel has been identified as an associate of corundum only in the gravel deposits in Macon County. At the Ruby mine on Cowee Creek and at the rhodolite mine on Mason Branch, gahnite has been found in the concentrates from the washing of the gravels for these gems. It has a clean, glassy fracture, like that of some dark obsidians, and is deep bottle-green by transmitted light. The octahedron (o) alone and in combination with the rhombic dodecahedron (d) were the only forms observed on the crystals. The faces are never smooth, but have an irregular and rounded appearance very similar to the so-called "fused quartz." Smooth fragmentary masses are the most common, varying in size from 3 mm. to 1.5 cm. in diameter and are very free from inclusions.

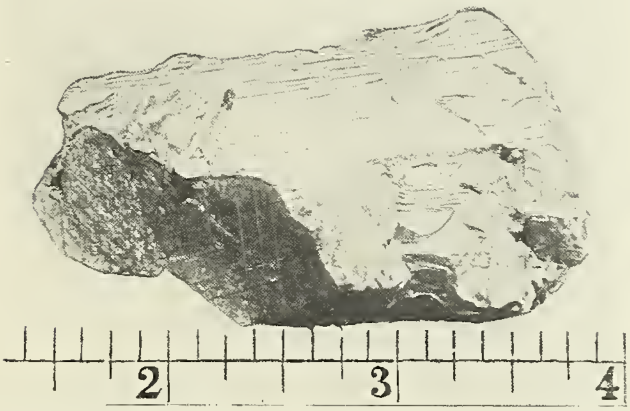
Its hardness is between 7.5 and 8 and its specific gravity is from 4.24 to 4.40. It has been analyzed by Dr. Charles Baskerville with the following results:

Analysis of gahnite from Ruby mine, Macon County.

		Ratio.	
Al_2O_3	61.09	.599	1.13
FeO	7.78	.108	
ZnO	27.44	.339	.530 = 1.
MgO	3.30	.083	
	99.61		



A, SPINEL IN RADIATING CHLORITE NODULE, CORUNDUM HILL (SHAFT), MACON COUNTY, N. C.



B, CORUNDUM AND MUSCOVITE, PRESLEY MINE, HAYWOOD COUNTY, N. C.

From the above analysis it is seen that the mineral is kreittonite or the zinc-iron variety of gahnite. The ratio of Zno : FeO : MgO is close to 12 : 4 : 3, which would give the formula for this gahnite (12Zn.4Fe.3Mg) $O.Al_2O_3$.

10. Magnetite.

Magnetite crystallizes in the isometric system with the octahedron as the common form. It is readily recognizable by its strong magnetic properties. Its composition is a combination of the protoxide and sesquioxide of iron, represented by the formula $FeFe_2O_4$ (or both). In hardness it varies from 5.5 to 6.

Besides the occurrence of the magnetite intimately associated with corundum in emery (see description of emery, p. 192), it is also found as an associated mineral and as an alteration product of chrysolite (olivine). In the early stages of the decomposition of the peridotites there is commonly a deposition of magnetite in fine grains which forms a network of black lines that often outline the original chrysolite grains after the whole has passed into serpentine. Again, magnetite has been deposited in the form of perfect octahedral crystals, occurring in the serpentine and talc. These crystals are usually very small, from 1 to 2 millimeters in diameter.

At the peridotite formation on the Arthur Woody farm, 2½ miles southeast of Bakersville, perfect octahedral crystals of magnetite 1 mm. in diameter have been found. These are nearly perfect in their development and have a rich, splendent luster.

Magnetite has been found at the Corundum Hill mine in seams from 3 to 4 inches thick, at an opening near the north side of the hill. This is the largest seam or deposit of magnetite observed that is the result of the direct alteration of the peridotite.

11. Chromite.

This mineral is between iron-black and brownish black in color and has a sub-metallic luster. Its hardness is 5.5. The chemical composition has usually been represented by the formula $FeCr_2O_4$ (or $FeO.Cr_2O_3$), where part of the iron may be replaced by magnesium and the chromium by aluminum and ferric iron (see page 375 for further description).

An octahedral parting, which apparently has not been observed in this mineral before, has been found in that which occurs in dunite near Webster, Jackson County. So far as could be determined in the sections it is in every way similar to that found in other spinels (Pl. XLII, fig. 2).

Chromite or chromic iron, the ore of chromium, is present in all the peridotite formations that have been examined in North Carolina. It occurs in grains and crystals and frequently in imbedded masses near the contact of this rock with the gneiss or other country rock. It is usually massive, and from fine granular to compact, but sometimes it is found in small but perfect octahedral crystals similar to the magnetite described above. The best crystals have been obtained from the alluvial deposits, where in the disintegration of the enclosing rock the chromite crystals have been left intact and have been deposited in the gravels. At the Corundum Hill mine perfect octahedral crystals were found that were up to 1.5 mm. in diameter.

11a. Mitchellite.—This mineral is a variety of chromite in which the iron oxide is largely replaced by magnesia. The only locality where it has been found is in the peridotites near Webster.

In appearance this chromite is different from any other that has been observed, having a much more coarse-grained appearance than ordinary chromite.

The analysis of this mineral, by Dr. H. W. Foote, from which was deduced the formula $2MgO.Al_2O_3$; $MgO.Cr_2O_3$; $FeO.Cr_2O_3$, is given below, together with the theoretical composition.

Chemical analysis and theoretical composition of mitchellite.

		Theory for $2MgO.Al_2O_3$: $MgO.Cr_2O_3$; $FeO.Cr_2O_3$.
Cr_2O_3	39.95	40.90
Al_2O_3	29.28	30.44
FeO	13.90	10.75
MgO	17.31	17.91
	100.44	100.00

The name mitchellite was given to this mineral in honor of the late Professor Elisha Mitchell, of North Carolina.

Chromite is a very stable mineral but instances have been noted where chlorite and kämmererite have been derived in part from it (see pages 75 and 319).

12. Rutile.

This mineral crystallizes in the tetragonal system, the prismatic forms being the common type. It is from 6 to 6.5 in hardness and has a reddish brown to red color, with a metallic to adamantine luster. Its chemical composition is represented by the formula TiO_2, a titanium oxide.

Rutile is rarely associated with corundum. Dr. Genth mentions its occurrence at the Corundum Hill mine in small grains or crystals and states that it is very rare. It is quite abundant, however, associated with corundum, in the gravel deposits of Mason Branch, and Caler Fork of Cowee Creek, Macon County. It is in fragments and rough crystals measuring from a few millimeters to one or two centimeters in diameter. Corundum has been found at Crowder's and Chubb's mountains, Gaston County, that contains crystals of rutile of different sizes disseminated through it. A peculiar occurrence of this mineral is as minute hair-like inclusions in the rubies of Macon County, described on pp. 183 and 190.

HYDROUS OXIDES.

13. Diaspore.

This mineral crystallizes in the orthorhombic system, the crystals usually being prismatic and flattened parallel to the brachypinacoid or *b*(010) face and with a *b* cleavage very prominent. The luster is brilliant and vitreous except on the cleavage face, which is pearly, and the color is whitish to grayish white. Its hardness is 6.5 to 7. The composition is AlO(OH), a hydrous oxide of alumina.

Although this mineral is a common associate of most of the emery deposits and has been found at some of the corundum deposits in other States, it has been identified at only one locality in North Carolina. Mr. J. C. Trautwine[7] has described very minute acicular crystals of diaspore that were found in cavities of massive corundum from the Corundum Hill mine. A careful search at this and other corundum mines in the State has failed to reveal any other specimens of this mineral.

It is not at all improbable that diaspore is the result of the alteration of corundum and that it occurs with it in a very finely divided state at many localities. The various amounts of water that are found in corundum from different localities could readily be explained on the supposition that diaspore is the resultant mineral due to the direct hydration of corundum, which may have been carried to only a very slight extent.

14. Limonite.

This mineral is readily recognized and identified by means of its yellowish to brown color and mamillary to botryoidal structure, and its yellowish streak.

This hydrous oxide of iron $Fe_2(OH)_6Fe_2O_3$ or $(2Fe_2O_3.3H_2O)$, sometimes called brown hematite, has been observed at a number of the peridotite formations as a final alteration of some of the minerals rich in iron.

In Clay County, near Elf, geodes of limonite were found that contained a considerable quantity of loose vermiculite (see p. 114). Some of these geodes would hold nearly half a bushel. This mineral is also sometimes the result of the final weathering of the peridotites and in some instances it has been segregated so as to make deposits of iron ore of commercial value.

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[7] Jour. Franklin Inst., Vol. XCIV, 1872, p. 7.

CARBONATES.

Only a few carbonates have been found at any of the corundum localities and those are undoubtedly of secondary origin. They have been found in association with corundum in peridotite rocks.

15. Magnesite.

Magnesite crystallizes in the rhombohedral division of the hexagonal system, the unit rhombohedron being the common form observed. It usually exhibits a perfect rhombohedral cleavage and has a hardness of 3 and a specific gravity of 3 to 3.12. In color it varies from white to yellowish and has a vitreous luster. Chemically it is a magnesium carbonate, represented by the formula $MgCO_3$ or $MgO . CO_2$.

Occasionally there is developed in the joints of the chrysolite from many of the peridotite localities a carbonate which, under the microscope, is seen to have a rhombohedral cleavage and a high double refraction. A qualitative analysis of this mineral identified it as magnesite. It occurs at a number of the peridotite localities but only very sparingly at any of them. Occasionally some is found from which distinct cleavage rhombohedrons can be obtained. Near Webster, Jackson County, a white earthy variety has been found and at Mine Creek, Yancey County, a white compact variety.

15a. Breunnerite, a magnesite containing a low percentage of iron, has been found in the serpentine 4 miles south of Morganton, Burke County, and near Dodson, Surry County, but has not been recognized in direct association with corundum.

16. Aragonite.

This mineral crystallizes in the orthorhombic system, but the crystals are usually hexagonal in outline, by reason of twinning. It does not have a very distinct cleavage. It is from 3.5 to 4 in hardness and usually white in color. Aragonite is a calcium carbonate, $CaCO_3$ or $CaO . CO_2$.

At a number of corundum mines, principally the Corundum Hill mine, there were found white radiated, star-like incrustations, that had the luster and appearance of deweylite (see fig. 28). When tested, these were found to be made up of a carbonate, in a matrix of the deweylite. No distinct crystals of the carbonate were observed, but when the mineral was examined under the microscope, its optical and crystallographic properties were seen to be orthorhombic. It was carefully separated from the deweylite and a pure product obtained for analysis. Its specific gravity is 2.91. This product was analyzed by Dr. H. W. Foote[8] with the following results:

Analysis of aragonite from Corundum Hill mine, Macon County.

		Ratio.
CO_2	43.22	.982
CaO	54.67	.976
MgO	0.89	...
SiO_2	0.36	...
Fe_2O_3	0.18	...
Ins. Res.	0.28	...
	99.60	

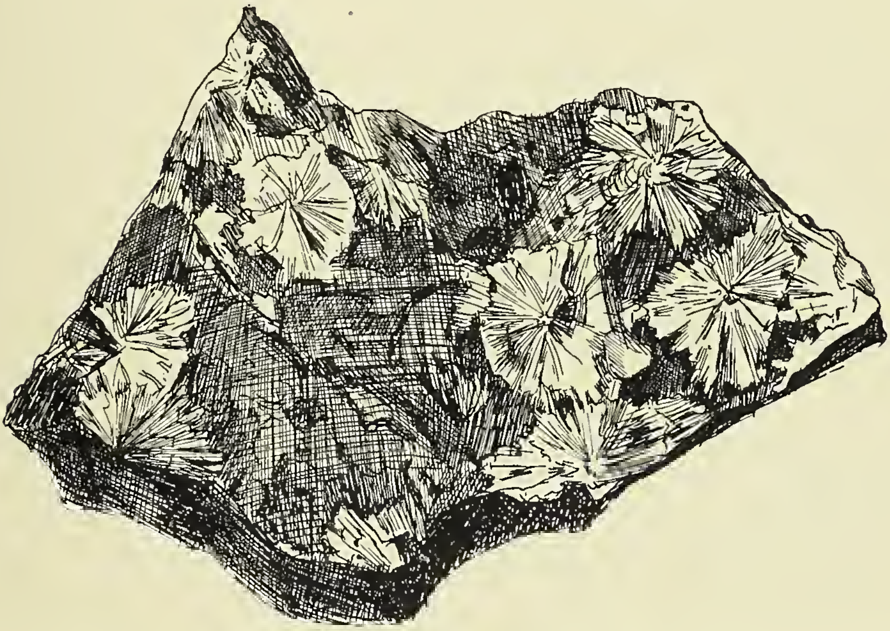

FIG. 28.—Star-like incrustations of aragonite on deweylite; Corundum Hill mine, Macon County, N. C.

In the above analysis the ratio of CO_2 : CaO is .982 : .976, which is practically 1 : 1, and which shows that the mineral is chemically calcium carbonate, $CaCO_3$. From the crystallographic and chemical properties, this carbonate is known to be the mineral aragonite.

This mineral has also been found very sparingly at the Carter mine, Madison County, and the Buck Creek mine, Clay County, and at both these localities it was in the single star-like incrustations.

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[8] Of the Sheffield Scientific School, New Haven, Conn.

SILICATES.

The silicates form by far the largest class of the alteration and associated minerals of corundum, and are divided into anhydrous and hydrous silicates. Many of these were derived directly from the alteration of the peridotite; others were aided in their formation by the corundum; and still others were formed from the same general magma as the corundum.

ANHYDROUS SILICATES.

The Feldspars (17-21).

There are two distinct classes of feldspars, the potash and the soda-lime (plagioclase). Only members of the latter group, however, have thus far been found associated with corundum. They have many characteristics in common. All crystallize in the monoclinic or triclinic systems and in forms that closely resemble one another; they all have cleavage in two directions, at nearly 90° to each other, so that they occur in rectangular masses; their hardness is about 6, a little harder than steel; and in color they are nearly white, though they sometimes present pale shades of red, yellow, and green.

In the plagioclase feldspars the twinning plane is parallel to the brachypinacoid, and the twinning is usually repeated in the form of thin lamellæ, giving rise to fine striations on the basal cleavage surface. By means of these striations a feldspar can usually be readily identified as belonging to the plagioclase group, but to determine the species to which it belongs a chemical analysis, a specific gravity determination, or a microscopical examination is necessary.

17. Albite.

This feldspar is not at all a common associate of corundum in peridotite and has been observed at but one locality, the Buck Creek mine, in Clay County, where it occurs very sparingly. At the Presley mine, in Haywood County, albite is associated with corundum and muscovite in the pegmatitic dikes. Albite is also associated with corundum in some of the occurrences of corundum in gneiss.

18. Oligoclase.

This mineral has been found at the Corundum Hill mine, where it is associated with black tourmaline; it has also been found at the Carter mine in Madison County. That from the Corundum Hill mine has been analyzed by Mr. H. M. Keller,[9] as follows:

Analysis of oligoclase from Corundum Hill mine, Macon County.

SiO_2	63.32
Al_2O_3	35.19
CaO	5.01
Na_2O	8.02
K_2O	0.25
	101.79

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[9] Bull. U. S. Geol. Survey No. 74, p. 55.

19. Andesine.

Andesine occurs in the Buck Creek mine in snow-white and bluish-white masses, showing distinctly the fine striæ on the basal cleavage plane, and is associated with black hornblende. In the same mine a fine-grained andesine is associated with zoisite and margarite. The first (I) has been analyzed by Mr. G. A. Koenig[10] and the latter (II) by Mr. T. M. Chatard.[11]

Analyses of andesine from Buck Creek mine, Clay County.

	I.	II.
SiO_2	57.29	58.41
Al_2O_3	26.52	25.93
Fe_2O_3	0.21	0.38
MgO	0.15	0.18
CaO	7.80	5.82
Na_2O	6.75	6.45
K_2O	0.33	2.10
Loss by ignition	1.43	0.93
	100.48	100.20
Specific gravity	2.611	2.610

This feldspar has also been found at the Bad Creek mine, Sapphire, Jackson County.

20. Labradorite.

This feldspar has been identified at but one of the corundum localities, the Buck Creek mine, where it occurs in small white, lustrous, cleavable masses, which show but few of the striæ. It has been analyzed by Mr. W. H. Jarden,[12] with the following results:

Analysis of labradorite from Buck Creek mine, Clay County.

SiO_2	55.61
Al_2O_3	26.90
CaO	9.60
Na_2O	6.97
K_2O	0.55
Loss on ignition	0.35
	99.98

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[10] Proc. Am. Phil. Soc., Vol. XIII, 1873, p. 375.

[11] Ibid.

[12] Bull. U. S. Geol. Survey No. 74, p. 54.

21. Anorthite.

This feldspar forms with olivine a mass of troctolite that outcrops over an area of about two acres at the extreme eastern border of the peridotite outcrop at Buck Creek (for description of this rock see page 76). The particles of anorthite vary in size from that of a pea to nodules an inch and a half long by three-quarters of an inch broad, and are separated from the olivine by a zone of silicates, composed partly of enstatite (see Pl. XXXVIII).

There is a similar occurrence of anorthite at Shooting Creek, Clay County.

In the grass-green amphibolite dikes, containing nodules of pink corundum, that occur with the peridotites at Buck Creek, there is a triclinic feldspar which agrees both in specific gravity and extinction angles with anorthite. Partial analyses of this anorthite are given on page 85, which confirm the results of the physical tests.

PYROXENE GROUP.

There are three divisions of the minerals in this group, according as they crystallize in the orthorhombic, monoclinic, or triclinic systems. Of these the first two are the more important. They closely resemble one another in chemical composition and physical properties.

ORTHORHOMBIC DIVISION.

22. Enstatite.

Enstatite crystallizes in the orthorhombic system but distinct crystals are rare, and their habit is prismatic, with angles of nearly 90°. It is usually massive to fibrous and has a nearly perfect prismatic cleavage. Its hardness is 5.5 and when massive it forms a very tough rock. In color it is a grayish white, and yellowish to brown, the darker varieties containing a larger percentage of iron oxide.

Chemically enstatite is a magnesium silicate, $MgSiO_3$; but there is usually a little ferrous oxide isomorphous with the magnesia and as this increases the mineral becomes darker in color and passes through bronzite to hypersthene.

Enstatite occurs not only as a rock constituent in harzburgite (saxonite), pyroxenite, and enstatolite, but it has been found at many of the corundum localities as one of the alteration products or vein minerals.

Enstatite is often mistaken for anthophyllite, the orthorhombic amphibole, and at many of the corundum localities, more noticeably at the Corundum Hill mine, North Carolina, and the Laurel Creek mine, Georgia, the mineral that is commonly called anthophyllite is enstatite. That from Corundum Hill occurs in the vein between the corundum and the unaltered dunite. It is a mass of interlocking bladed grayish crystals, that is very tough and tenacious.

This mineral has been analyzed by Dr. Baskerville with the following results:

Analysis of enstatite from Corundum Hill, Macon County.

		Ratio.	
SiO_2	51.64	.861	
Al_2O_3	0.12	.001	
FeO	9.28	.129	
MnO	0.56	.008	.943
MgO	31.93	.798	
CaO	0.45	.008	
H_2O	5.45	.303	
	99.43		

The presence of water in the analysis shows that there was some serpentine or talc mixed with the enstatite analyzed.

At a number of the peridotite localities, a brownish enstatite has been sparingly found.

22a. Bronzite.—The occurrence of this variety of enstatite in any considerable amount in North Carolina was first mentioned by Dr. G. H. Williams,[13] who described specimens of a bronzite-diopside rock, to which he gave the name websterite. These specimens were from the Webster peridotite area described on page 92 (see Pl. VIII).

Near the northern end of the dunite outcrop, at the side of the road, boulders were observed, which when broken open were found to be composed almost entirely of bronzite. Besides the boulders, a few masses of the same rock have been observed in situ.

The bronzite composing this rock is of a resinous brown color, and of a bronze-like luster, even on the unaltered surfaces. On the cleavage surface the luster is decidedly pearly. No distinct crystals were observed, the specimens being a mass of interlocking crystals making a very tough rock similar to the enstatite described above. In most of the specimens the crystals were so interlocked that no crystal outline of these could be distinguished. In a few of the specimens the crystals were much larger and their development and their outline could readily be detected. Some of the crystals measured 2 cm. in the direction of the *b* axis.

The material for analysis was hand picked and that selected showed no impurities or decomposition when examined with the magnifying glass.

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[13] American Geologist, VI, 1890, p. 43.

The results of an analysis by Dr. Baskerville are given below:

Analysis of bronzite from near Webster, Jackson County.

		Ratio.		
SiO_2	53.62	.894		= 100
Al_2O_3	.97	.009	.012	
Cr_2O_3	.50	.003		
FeO	9.06	.125	.994 =	1.11
CaO	1.75	.031		
MgO	33.53	.838		
H_2O	0.19			
	99.62			

In the above analysis the ratio of the bivalent oxides to the silica (SiO_2) is close to 1:1, and of ferrous oxide (FeO) to magnesia (MgO) and lime (CaO) is very near 1:7; this would give the formula, $(MgFe)SiO_3$, with Mg : Fe = 7 : 1, for this mineral.

Associated with the bronzite is the emerald-green diopside mentioned by Williams, which is sparingly scattered through the rock in very small, clear, green grains.

The name bronzite is very appropriate to this enstatite, for the luster is decidedly bronze-like throughout the entire mass. A similar bronzite, showing the same decided bronze-like luster, has been found on Cane Creek, 3 miles east of Webster, and also at the Buck Creek (Cullakeenee) corundum mine in Clay County.

23. Hypersthene.

Hypersthene is very similar to enstatite, into which it passes with loss of ferrous oxide. Its optical and crystallographic properties are also dependent upon this variation in its content of ferrous oxide. It varies in color from dark brownish green, grayish, and greenish black to brown. Its chemical composition is represented by the formula $(FeMg)SiO_3$ where the ratio of Fe : Mg varies from 1 : 3 to nearly 1 : 1.

This mineral is not commonly associated with corundum, but at one locality, on the headwaters of Shooting Creek in Clay County, as a constituent of a hypersthenite dike it is directly associated with corundum. This rock is described on page 72.

MONOCLINIC DIVISION.

24. Pyroxene.

This mineral crystallizes in the monoclinic system and the common habit is prismatic, the prism angles being nearly 90°. It varies in color, being nearly colorless, white, brown, black, or green, sometimes very bright green, the color depending upon the chemical composition.

The different varieties of pyroxene are found but sparingly at the corundum localities and only as a constituent of websterite (the variety diopside) does it reach any importance. The variety diallage is sometimes observed with the chrysolite grains composing the dunite.

24a. Diopside.—This variety of pyroxene is a calcium magnesium silicate, represented by the formula $CaMg(SiO_3)_2$, and in color is white, yellowish to pale green, sometimes dark green or nearly black. Traces of chromium often give a very bright green color.

It occurs very abundantly as a constituent of the websterite found in the peridotite area near Webster, Jackson County, and the chrome diopside has been found sparingly with the bronzite described above.

24b. Diallage.—This variety is similar in chemical composition to diopside, but sometimes contains a considerable per cent of aluminum. It is characterized by a fine lamellar structure.

It occurs very sparingly in dunite from some of the peridotite localities. It is a natural constituent of the peridotites, lherzolite, and culysite.

Both the orthorhombic and monoclinic pyroxenes follow the same general laws in the development of alteration products, and the change is usually to hornblende and from this to talc. The pyroxenes are sometimes original constituents of the rocks, but in some cases they are very evidently a secondary product. This is especially true of the enstatite variety.

AMPHIBOLE GROUP.

The amphibole group, like the pyroxene group, contains a number of mineral species that crystallize in the orthorhombic, monoclinic, and triclinic systems, and that are very closely related to one another in chemical composition, and in crystallographic and optical properties. They are also closely allied to the pyroxene group, and it is often difficult to distinguish them from one another chemically. Although there is a close relationship between them in crystalline form, they can be readily distinguished by their prismatic angle and cleavage, that of pyroxene being 87° and 93° and of amphibole 56° and 124°.

The minerals of the amphibole group consist chiefly of lime, magnesia, and ferrous oxide silicate, often containing soda, potash, alumina, and ferric oxide, and may be represented by the general formula $RSiO_3$, and with $R''R'''_2SiO_6$, where $R'' = Ca,Mg,Fe,Na_2,K_2$ and $R''' = Al,Fe$.

ORTHORHOMBIC DIVISION.

25. Anthophyllite.

Anthophyllite crystallizes in the orthorhombic system and with a prismatic habit. The crystals are rather rare, and are seldom terminated. It is commonly lamellar or fibrous.

> Its cleavage is perfect, prismatic, and in color it is brownish gray, yellowish brown, clove-brown, and brownish green. Chemically it is a magnesian, ferrous oxide silicate, represented by the formula (MgFe) SiO_3. Alumina is sometimes present in considerable amount.
>
> Anthophyllite is nearly or quite infusible and contains little or no lime, and may thus easily be distinguished from the monoclinic amphiboles, which are readily fusible, and contain much calcium oxide.

The anthophyllite, which has been reported in quantity from several corundum localities, has proved to be enstatite. As a direct associate of corundum anthophyllite is not common, but as a rock constituent it has been found at a number of the peridotite formations.

The most important locality, and in fact the only one in the United States where good crystals of anthophyllite have been found, is at the Woody place, 2½ miles south of Bakersville, Mitchell County, on the Marion road. The hillside where it occurs is quite barren and thickly scattered with loose fragments and boulders of altered dunite. The outcrop has been carefully examined but the anthophyllite has been found only in the boulders. The mineral occurs in prismatic crystals imbedded in penninite. Nearly all the crystals are seamed and cracked and those near the outer part of the boulders are somewhat decomposed and stained a dirty brown. The purest crystals are transparent, and vary from pale clove-brown to a flesh color.

The crystals measure from 2 mm. to 6 mm. in the widest diameter, and some were over 3 cm. in length. A great many crystals were examined, but no terminated ones were observed. The unit prism, 110, occurring alone, or in combination with the brachypinacoid, 010, were the only forms observed.

This anthophyllite was formerly described by Prof. S. L. Penfield[14] as occurring at the Corundum Hill mine. He made an analysis of the mineral (II, below), and it has also been analyzed by Dr. Charles Baskerville (I, below).

Analyses of anthophyllite from Woody Place, near Bakersville, Mitchell County.

	I.	II.	Ratio.	
SiO_2	56.40	57.98	.966	
Al_2O_3	1.15	0.63	.006	
FeO	11.40	10.39	.144	.963
MnO	....	0.31	.005	
MgO	28.68	28.69	.717	
CaO	0.50	0.20	.004	
H_2O	1.63	1.67	.093	
Loss at 100° C.	....	0.12		
	99.76	99.99		

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[14] Am. J. Sci., Vol. XL. 1890, p. 394.

In the above, the ratio of SiO_2 to the basic oxides RO (including H_2O) is .966 : .963 or almost exactly 1 : 1, giving the formula $RSiO_3$, where R = Mg, Fe, H_2 and traces of Mn and Ca. Experiments made by Penfield[15] have shown that the H_2O is an essential constituent of the mineral and not the result of alteration.

White prismatic crystals of anthophyllite are also sparingly found at this locality.

One specimen of a true anthophyllite has been found at the Corundum Hill mine, but this was more fibrous and not of such good quality as that from the Woody Place. At the Buck Creek corundum mine, brown prismatic crystals of anthophyllite have been found rather sparingly.

As a secondary constituent of dunite, this mineral occurs at Corundum Hill in long, slender needles penetrating the rock in every direction (Pl. XL, fig. 2) in exactly the same manner as cummingtonite or tremolite in other localities (see foot-note, p. 67). The rock is described on p. 88.

MONOCLINIC DIVISION.

26. Amphibole.

Some of the different varieties of amphibole are found at nearly all of the corundum localities. In some instances it forms a considerable proportion of the vein minerals, while at others it is found but sparingly. It is, of course, abundant as a constituent of the amphibolites.

Amphibole crystallizes in the monoclinic system, with the crystals commonly prismatic. It is sometimes fibrous, coarse or fine, and also granular massive. The prismatic cleavage is perfect. The luster is vitreous to pearly and in the fibrous varieties silky. In color it varies from black to white, through various shades of green and brown.

In composition it is generally analogous to the pyroxenes and is a normal metasilicate of calcium and magnesium, usually with iron and often with manganese, aluminum and the alkali metals, sodium and potassium.

26a. Tremolite.—This mineral is the calcium magnesium variety of amphibole and its chemical composition is expressed by the formula $CaMg_3(SiO_3)_4$. Ferrous oxide sometimes sparingly replaces magnesia. Its color varies from white to dark gray.

A tremolite-like mineral has been found at many of the corundum localities in North Carolina, in long, slender needles, which penetrate the chrysolite grains in every direction, and is undoubtedly of secondary origin. It is not improbable, however, that it would often prove, on chemical examination, to be cummingtonite, as described below (No. 26*f*).

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[15] Loc. cit., p. 397.

26b. Actinolite.—This is the calcium-magnesium-iron variety of amphibole, whose formula is $Ca(MgFe)_3(SiO_3)_4$. Its color is usually bright green to grayish green.

It occurs at many of the corundum localities, especially at the Corundum Hill mine, where it has been found in long, slender, bright-green crystals, 3 to 5 inches in length.

The amphibole of the amphibole-peridotites, which occur in many localities, is often actinolitic in appearance, but is doubtless usually aluminous.

26c. Edenite.—Edenite is one of the aluminous amphiboles, and is of a white to gray and pale-green color. As the percentage of iron increases, the edenite passes through the green pargasite to the dark colored or black hornblende.

The corundum-bearing amphibolite dikes that are found associated with the peridotites at Buck Creek, Clay County, are composed principally of a grass-green amphibole and anorthite. This rock is described on page 83.

This amphibole has usually been referred to the variety smaragdite, but the chemical analyses of the mineral show that it should be classed with the variety edenite. When the minute particles or powder of this mineral were examined under the microscope many particles of chromite or picotite were observed and the color was always a deeper green directly surrounding them. The purer mineral, separated by the heavy solution, was analyzed by Dr. Baskerville. The results of this analysis are given below (I), also of an analysis of the same mineral by Dr. Genth (II), in which there was no separation of the picotite.

Analyses of edenite from Buck Creek, Clay County.

	I.	II.
SiO_2	44.38	45.14
Al_2O_3	17.32	17.59
Cr_2O_3	0.38	0.79
FeO	3.83	3.45
NiO	....	0.21
MgO	15.48	16.69
MnO	0.90	....
CaO	11.51	12.51
Na_2O	1.24	2.25
K_2O	0.38	0.36
Loss on ignition, H_2O	4.63	1.34
	100.03	100.33
Specific gravity	3.075	3.120

The higher specific gravity and the greater percentage of chromium oxide (Cr_2O_3) in the mineral analyzed by Dr. Genth are probably due to the presence of picotite or chromite inclusions. The grass-green color of the edenite is without doubt also due to the presence of the chromic oxide.

26d. Asbestos.—Tremolite, actinolite, and many of the non-aluminous varieties of amphibole are at times very fibrous, the fibers being sometimes very long, flexible, and easily separated with the fingers and looking somewhat like flax. These are also called asbestos.

Much of the material that is called asbestos is chrysotile, a fibrous variety of serpentine. It has been found at many of the peridotite formations, and at some, in sufficient quantity to make it of considerable economic importance. These localities are described on page 390.

26e. Hornblende (pargasite and common hornblende).—This variety of amphibole varies in color from bright or dark green, bluish green, to grayish black and black. Pargasite usually includes the green colors and the common hornblende the darker colors.

At nearly all of the corundum localities there is more or less of the green hornblende, some of which is in good prismatic crystals. At the peridotite locality near the Micaville ford, Yancey County, brown crystals of hornblende were found.

A deep black hornblende occurs with the corundum at the Buck Creek mine, and makes up a considerable portion of the vein. Some of this hornblende gives a strong soda reaction, and was classified as arfvedsonite, but the chemical analysis showed only a low per cent of soda. It does not fuse as readily as arfvedsonite, whose fusibility is 2.

The mineral was analyzed by Dr. J. L. Smith[16] with the following results:

Analysis of hornblende from Buck Creek mine, Clay County.

SiO_2	45.90
Al_2O_3	13.34
Fe_2O_3	11.46
CaO	12.20
MgO	12.53
Na_2O	3.39
H_2O	0.66
	99.48

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[16] Bull. U. S. Geol. Survey No. 74, 1891, p. 45.

The true arfvedsonite contains about 8 per cent of soda (Na_2O), while the above mineral contains but 3½ per cent.

Black hornblende is also quite abundant at the Bad Creek mine, in Jackson County.

26f. Cummingtonite.—This mineral is almost identical in composition with anthophyllite, but optically it is monoclinic and is often called amphibole-anthophyllite. It has been observed at a number of localities, especially at the dunite localities about Sapphire, Jackson County, and at the Corundum Hill mine, Macon County, as minute needle-like colorless prisms penetrating the grains of olivine of the dunite in every direction. It possesses the physical and optical properties of tremolite, but chemical examination proves the absence of lime, which is always present in tremolite.

27. Arfvedsonite.

Dr. Genth[17] has reported the occurrence of this mineral at the Corundum Hill mine, but it was probably a hornblende.

GARNET (28, 29, and 30).

Under this head are included a series of minerals that are orthosilicates, having the general formula $R''_3R'''_2(SiO_4)_3$, where $R'' =$ Ca, Mg, Fe, and Mn and $R''' =$ Al, Fe and Cr. They crystallize in the isometric system, the dodecahedron and trapezohedron being the common forms, either alone or in combination. The hardness is from 6.5 to 7.5. The specific gravity varies from 3.5 to 4.3 according to the chemical composition, which also causes the color to vary from pink, red, brown, yellow, white, green to black.

In the following table are given the different varieties of garnet, with their chemical composition:

I. Aluminous garnets.

Grossularite	$Ca_3Al_2(SiO_4)_3$
Pyrope	$Mg_3Al_2(SiO_4)_3$
Rhodolite	$2Mg_3Al_2(SiO_4)_3 . Fe_3Al_2(SiO_4)_3$
Almandite	$Fe_3Al_2(SiO_4)_3$
Spessartite	$Mn_3Al_2(SiO_4)_3$

II. Iron garnets.

Andradite	$Ca_3Fe_2(SiO_4)_3$

III. Chromium garnet.

Uvarovite	$Ca_3Cr_2(SiO_4)_3$

Of these varieties of garnet, but three have been found directly associated with corundum, and these are rhodolite, almandite, and andradite.

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[17] Bull. U. S. Geol. Survey No. 74, 1891, p. 118.

28. Rhodolite.

This garnet is remarkable for its color and beauty as a gem stone. It has a peculiar and beautiful tint that is in part similar to that belonging to the rhododendron and rose, and this, combined with its transparency and brilliancy, is most striking in artificial light.

It is found associated with the rubies in the Cowee valley, Macon County (see p. 182) and is usually in waterworn fragments or pebbles in the gravels of this district. The only crystals that have been found are very minute, occurring as inclusions, and they are sometimes rhombic dodecahedrons and at others trapezohedrons.

Many of the ruby crystals from this locality bear impressions which, when a wax mold of them has been taken, are seen to be of garnet. Other rubies have been broken open and minute rhodolites have been found in them. Corundum crystals have also been found wholly and partially surrounding rhodolite. This association of garnet and corundum has been represented in fig. 16, p. 183.

Some carefully selected pieces of this mineral, of a pale rose tint, having a specific gravity of 3.837 to 3.838, were analyzed with the following results:

Analyses of rhodolite from Mason Branch, Macon County.[18]

	I.	II.	III.	Average.	Ratio.	
SiO_2	41.54	41.65	....	41.59	.693 = 3.00	
Al_2O_3	....	23.26	23.10	23.13	.226	.237 = 1.02
Fe_2O_3	1.88	1.92	....	1.90	.011	
FeO	15.48	15.63	....	15.55	.216	
MgO	....	16.90	17.48	17.19	.429	.661 = 2.89
CaO	1.02	.86	....	.92	.016	

The ratio of $R''O : R'''_2O_3 : SiO_2$ is nearly 3 : 1 : 3, which would give the general formula $3R''O . R'''_2O_3 . 3SiO_2$, or $R''_3R'''_2(SiO_4)_3$, which identifies this mineral as a garnet. The ratio of MgO : FeO (.437 : .216) is almost exactly 2 : 1, which would indicate that the mineral is composed of two molecules of a magnesium-aluminum garnet (pyrope) and one molecule of a ferrous-iron-aluminum garnet (almandite). The theoretical composition calculated for this ratio is given below, together with the analysis after substituting for Fe_2O_3 its equivalent of Al_2O_3 and for CaO its equivalent of MgO and then recalculating to 100 per cent.

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[18] By Joseph Hyde Pratt.

Theoretical chemical composition of rhodolite.

	Analysis Recalculated	Theory for $2Mg_3Al_2(SiO_4)_3 ; Fe_3Al_2(SiO_4)_3$.
SiO_2	41.76	41.48
Al_2O_3	24.41	23.50
FeO	15.62	16.59
MgO	18.21	18.43
	100.00	100.00

Although the agreement of the analysis, as deduced, and the theory is not absolutely exact, yet it must be regarded as satisfactory, and the formula $2Mg_3Al_2(SiO_4)_3 . Fe_3Al_2(SiO_4)_3$ may be accepted for this mineral.

The name rhodolite has been given to this garnet from the resemblance of its color to that of certain roses and rhododendrons.

29. Almandite.

This garnet, which is also known as precious garnet, is of a deep rich red to pink color and its composition is represented by the formula $Fe_3Al_2(SiO_4)_3$, where part of the alumina is replaced by ferric oxide and part of the ferrous oxide by magnesia.

It has been found abundantly at many of the corundum localities, especially those where the corundum occurs in gneiss and schist; as on Scaly Mountain, Clay County, N. C.

30. Andradite.

Andradite, common or black garnet, is occasionally found with the corundum in the mica-schist and some has been observed with the corundum in the peridotite at the Bad Creek mine. The composition of this garnet is $Ca_3Fe_2(SiO_4)_3$, where alumina replaces a portion of the ferric oxide and magnesia replaces part of the lime.

31. Chrysolite (olivine).

Chrysolite crystallizes in the orthorhombic system, but distinct crystals are not common in association with corundum. The color includes nearly all the shades from light brownish yellow to a dark green. The freshest specimens are an olive-green to yellowish green, and are transparent. The yellowish brown and red colors observed are due to the oxidation of the iron in the mineral. Chemically, chrysolite is a magnesium iron orthosilicate $(MgFe)_2SiO_4$, in which the ratio Mg : Fe varies widely, usually between the limits 9Mg : 1Fe to 2Mg : 1Fe.

It has been found directly surrounding corundum only at the Hayes mine, in Yancey County, and this occurrence is described on page 259. As a constituent of the peridotite rocks, chrysolite is an associated mineral of corundum at nearly all the corundum localities.

The chrysolite is in imbedded irregular and angular grains that are about the size of a grain of wheat. Sometimes the grains are much coarser, and occasionally large grains are scattered through the mass of finer grains. Most remarkable instances of this kind have been observed in the harzburgite near Balsam Gap, Jackson County, and on South Toe River, Yancey County (Anal. III, below), where individual grains sometimes attain a diameter of 5 or 6 inches, with cleavages distinctly developed. Under the microscope many of the smaller grains are seen to have a distinct cleavage parallel to the brachypinacoid; also, more rarely, a basal cleavage.

Analyses have been made of specimens of chrysolite from the following localities: The Corundum Hill mine (I),[19] the Webster peridotite area (II),[20] and the peridotite area 6 miles south of the forks of Toe River, Yancey County (III).[21] This last variety has been described on page 56.

Analyses of crysolite from Macon, Jackson, and Yancey Counties.

	I.	II.	III.
SiO_2	41.58	41.89	40.31
Al_2O_3	0.14	Trace.	....
FeO	7.49	7.39	9.58
MnO	....	....	0.19
NiO (Tr. Co & Mn)	0.34	0.35	....
MgO	49.28	49.13	49.26
CaO	0.11	0.06	....
Loss on ignition, H_2O	1.72	0.82	1.09
Cr_2O_3, etc.	....	0.58	....
	100.66	100.22	100.43

The above analyses approximate very closely to a chrysolite where the ratio of Mg : Fe is 9 : 1, of which the theoretical composition would be $SiO_2 = 41.0$, $MgO = 49.2$, $FeO = 9.8$.

Chrysolite is a mineral that suffers alteration very readily, often through the oxidation of the iron, the mineral becoming brownish or reddish brown and sometimes becoming entirely altered to limonite or an ocherous clay; also, by hydration, it alters to serpentine, the iron being removed in the form of grains or seams of magnetite or hematite. For a more detailed description of these and other modes of the alteration of chrysolite see "Alteration of the peridotites" (Chap. IV).

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[19] T. M. Chatard, Am. Phil. Soc., Vol. XIII, 1873, p. 362.

[20] Ibid., p. 362, and Am. J. Sci., Vol. XXXIII, 1861, p. 202.

[21] By Joseph Hyde Pratt.

31a. Villarsite.—It is not improbable that in the alteration of the chrysolite villarsite is formed, this being an altered chrysolite described from Traversella, France. An analysis of an altered chrysolite by Prof. C. U. Shepard[22] led him to place it under the head of villarsite. The result of the analysis was as follows:

Analysis of villarsite from Macon, Jackson, or Yancey County.

SiO_2	41.49
FeO	8.63
MgO	44.00
H_2O	5.69

The best specimens of chrysolite that have been found in North Carolina that show the largest, most transparent and best olive-green grains are from Webster and Balsam, Jackson County, and Mine Fork, Yancey County.

32. Meionite (Paranthite).

In Clay County, at the No. 2 mine of the Hiawassee Corundum Company, rounded masses, each a few ounces in weight, of a bluish gray mineral were found in a pocket that was near the center of a 6 foot corundum vein. This vein, composed of partially decomposed albite, chlorite, and vermiculite, with disseminated grains and crystals of corundum, lies between peridotite and hornblende-gneiss. Only this one pocket of the mineral has been found, and it was discovered by C. G. Memminger.

The mineral is in rounded crystalline lumps, and has a specific gravity of 2.75 and a hardness of 5.5. Chemically, it is a calcium-aluminum silicate, with a little soda and water, and has been analyzed by Mr. W. N. Berkely,[23] with the following results:

Analysis of meionite from Clay County.

		Ratio.	
SiO_2	47.54	.792	
Al_2O_3	34.03	.337	
CaO	17.23	.307	.336
Na_2O	1.82	.029	
H_2O	1.02	.056	
	101.64		

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[22] Am. J. Sci., 3d ser., Vol. IV, 1872, p. 112.

[23] Am. Chem. Jour., Vol. XIV, 1892, p. 628.

Mr. Berkely places this mineral under the scapolite group and states that as it does not contain any chlorine it must therefore be near the meionite end. These intermediate minerals between meionite and wernerite were formerly called parenthine or parenthite.

There is a large excess of silica in the above analysis, which may be accounted for by the meionite having suffered some alteration, and some mica having been formed.

This occurrence of a mineral of this type in association with corundum is the only one recorded. At the corundum localities in Clay County, more or less plagioclase feldspar has been found, and, as is well known, the scapolite minerals are often formed by the alteration of these feldspars. It is not, then, unreasonable to consider this mineral as the result of the alteration of the plagioclase feldspar that is found in the vein.

The exact location of this mine of the Hiawassee Corundum Company is not known, but it is supposed that it was near Elf, Clay County, N. C.

33. Sillimanite or Fibrolite.

This mineral crystallizes in the orthorhombic system and is usually in long, slender crystals without distinct terminations; that associated with the corundum is generally fibrous or fine columnar and sometimes radiated. In color it is grayish white to pale brown. It has a perfect cleavage parallel to the brachypinacoid and a hardness of 6 to 7. Its chemical formula is Al_2SiO_5 or $(AlO)AlSiO_4$ (Groth).

Sillimanite, which has for a long time been known to accompany corundum, has been identified at but few places in North Carolina. The most noted occurrence in the United States is near Norwich, Connecticut, where small crystals of blue corundum are completely surrounded by sillimanite.

Dr. Genth[24] has considered the fibrolite to be an alteration product of corundum and in some cases this is evidently true, as those described by him from Mineral Hill, Delaware County, Pennsylvania. At this place the corundum crystals, which are rough hexagonal prisms tapering at both ends, exhibit alteration from those where it has just begun, to some that still have a core of corundum remaining and others where there is not a trace, and true fibrolite pseudomorphs after corundum are left. Also those from near Laurens, South Carolina, which show hexagonal prisms of fibrolite on the exterior, but a core of corundum on the interior. At Shoup's Ford, in Burke County, North Carolina, fibrolite has been found that envelops crystals of corundum.

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[24] Am. Phil. Soc., Vol. XIII, 1873, p. 378.

It is very probable that much of the fibrolite found associated with the corundum in mica-schists and related crystalline rocks is a primary mineral with the corundum, and was formed during the metamorphism of these rocks.

34. Cyanite (or disthene).

Cyanite has the same chemical composition, Al_2SiO_5, as sillimanite, but crystallizes in the triclinic system and is commonly found in long, bladed crystals that are rarely terminated. The cleavage parallel to the macropinacoid (the widest face of the bladed crystals) is very perfect, while that parallel to the brachypinacoid is but little less perfect. Its hardness is 5 to 7, being readily scratched by steel in the direction parallel to the cleavage, but harder than steel at right angles to this. The color is usually blue, but at times is white, gray, light green to a deep grass-green.

Cyanite is a very common associate of corundum, the occurrences being very widespread, and while in some instances it may be the result of the alteration of corundum, it is, when found in gneisses and schists, more probably a primary mineral formed with the corundum.

At the Acme mine, near Statesville, Iredell County, pink corundum is found with an almost pure white, bladed cyanite. These are at times so blended that it is difficult to determine exactly where the corundum ends and the cyanite begins. The corundum is not in distinct crystals and is often in position parallel with the cyanite, which has all the appearance of being an alteration product of it.

In Transylvania County, on the West Fork of French Broad River, near the mouth of Owens Creek, crystals and grains of blue corundum have been found in boulders composed almost entirely of light green cyanite. At Coweeta, Macon County, pink corundum has been found in a mass of greenish cyanite.

35. Zoisite.

This mineral crystallizes in the orthorhombic system, but distinctly terminated crystals are extremely rare. The mineral is usually in prismatic crystals or crystalline masses, that are deeply striated or furrowed vertically. It is also sometimes columnar. The cleavage parallel to the brachypinacoid is perfect and it is 5 to 6.5 in hardness. It varies in color from white, grayish white, gray, yellowish brown, and apple-green to rose-red. The common color of that found associated with the corundum is white to grayish white, rarely greenish white.

Chemically zoisite is a basic calcium aluminum silicate having the formula $HCa_2Al_3Si_3O_{13}$ or $Ca_2Al_2(AlOH)(SiO_4)_3$ (Groth). Ferric oxide sometimes replaces a part of the alumina and thus it graduates toward epidote, which has the same general composition but is monoclinic.

Although this mineral is not a common associate of corundum, there are two localities where it is remarkably developed, at the Buck Creek mine and at Hogsed's, Shooting Creek, Clay County. At the latter place it is more coarsely columnar and in larger pieces and is often of an almost pure white color. At the former locality the zoisite is usually in rough, prismatic crystals and crystalline masses of a grayish white to white and greenish white color. It is intimately associated with corundum. At some places the corundum is imbedded in it and at others intricate masses of corundum, zoisite and margarite occur. It is also at times intimately associated with a plagioclase feldspar and has the appearance of having been derived from it. It may be that all the zoisite found associated with the feldspar and corundum is the result of the alteration of the feldspar.

A greenish white crystalline zoisite and a white to grayish white columnar zoisite from the Buck Creek mine have been analyzed, the former (I) by Mr. G. A. Koenig[25] and the latter (II) by Dr. F. A. Genth.[26] The results of the analyses are as follows:

Analyses of zoisite from Buck Creek mine, Clay County.

	I.	II.
SiO_2	40.70	39.86
Al_2O_3	33.86	33.84
Fe_2O_3	0.81	1.62
MnO	Trace.	Trace.
MgO	0.22	0.18
CaO	24.05	23.82
Na_2O (trace of Li_2O)	....	0.22
K_2O	....	0.09
Loss on ignition (H_2O)	0.63	0.78
	100.27	100.41
Specific gravity	3.286	3.224

36. *Epidote.*

In chemical composition, epidote is very similar to zoisite, the latter graduating into it by the replacement of its alumina with ferric oxide, but it crystallizes in the monoclinic system, with its crystals usually prismatic. The cleavage parallel to the base is perfect and its hardness is 6 to 7. The color peculiar to this mineral is a pistachio-green, but it is also yellowish and brownish green to black; also gray. The general formula for epidote is $HCa_2(AlFe)_3Si_3O_{13}$, the ratio of alumina to ferric oxide varying usually from 6 : 1 to 3 : 2.

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[25] Am. Phil. Soc., Vol. XIII, 1873, p. 373.

[26] Ibid.

It has been found only at two of the corundum mines. At the Bad Creek mine, Sapphire, Jackson County, small, slender green crystals of epidote occur with the amphibole, and at the Buck Creek mine, Clay County, in slender prismatic crystals, associated with tourmaline.

37. *Tourmaline.*

Tourmaline crystallizes in the rhombohedral division of the hexagonal system, and the crystals are usually prismatic, often slender to acicular. The prismatic faces are often striated vertically, which makes them rounded or barrel shaped. As the prism, *m*, $(10\bar{1}0)$ frequently predominates, the crystals have a decided triangular appearance. This is very apparent when a cross-section of the crystal is seen. They are brittle and often friable and have little or no cleavage. By these last three characteristics tourmaline can readily be distinguished from black hornblende, which it sometimes resembles. Its hardness is 7 to 7.5. Tourmaline has been found in nearly all colors—black, brown, green, blue, red, pink, and white. Only black tourmaline has thus far been found associated with the corundum.

Chemically it is a borosilicate principally of aluminum, iron, magnesium, some of the alkalies, hydrogen, and fluorine.

At the Corundum Hill mine, near what is called the Zeb Jones vein, black tourmaline has been found abundantly associated with corundum. The crystals were all well developed in the prismatic zone and rarely some showed partial pyramidal terminations. They varied from slender, acicular ones to some that were 5 mm. in diameter. The tourmaline occurs in masses of quartz and muscovite that carry some corundum. At times there is a mass of acicular crystals of the tourmaline through which there is scattered a little quartz and rarely a white to yellowish corundum.

Dr. Genth[27] describes two specimens of tourmaline from this locality, which he considers as alteration products of corundum. One of these is a small piece of a columnar crystal of tourmaline, the upper portion of which is corundum, the latter penetrating into a portion of the tourmaline. The tourmaline frequently contains a nucleus of corundum. The second specimen he mentions as a pseudomorph of tourmaline after corundum.

It is part of a crystal of reddish gray corundum a little over 2 inches in height and about 2 inches in thickness. It shows three planes of the hexagonal prism and portions of one pyramidal plane. At the upper part of this crystal, almost the entire corundum has been altered into black tourmaline, leaving only a shell of corundum of about one-eighth to one-quarter inch; at its lower part the corundum, although intermixed with tourmaline, is still about one inch in thickness. Plates of green chlorite penetrate both the corundum and the tourmaline.

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[27] Am. Phil. Soc., Vol. XIII, 1873, p. 377.

It is found in small quantity at the Buck Creek mine, Clay County, and the Sapphire mine, Jackson County. At Belts Bridge, Iredell County, star-like clusters of black tourmaline crystals occur on nodules of corundum, that are surrounded by chlorite, the tourmaline lying directly on the corundum.

38. Staurolite.

The crystals of staurolite belong to the orthorhombic system and are commonly prismatic in habit. Penetration twins are very abundant, the common twinning plane being the brachydome, *x* (032); the prisms crossing each other at nearly 90°. The cleavage parallel to the brachypinacoid is distinct but somewhat interrupted.

This mineral is rather brittle and has a hardness of 7 to 7.5. Its luster is vitreous but inclined to resinous, and in color is dark reddish brown to brownish black and yellowish brown. Most staurolite is translucent to opaque, but some has been found that is perfectly transparent and of gem quality.

The formula representing the chemical composition of staurolite is $HFeAl_5Si_2O_{13}$ or $Fe(AlO)_4(AlOH)(SiO_4)_2$, in which some of the alumina is replaced by ferric oxide and some of the ferrous oxide by magnesia. Most staurolite crystals are impure from mechanical admixtures, especially of quartz, while garnet, cyanite, magnetite, and mica have sometimes been observed.

This mineral has been found sparingly at a few of the corundum localities and is usually in small grains or particles that show no crystalline form. At the Corundum Hill mine a few minute brown grains of irregular shape and sub-vitreous luster were found. Perfectly transparent staurolite of a rich pyrope-garnet red color is found associated with the rubies in the gravels of Caler Fork of Cowee Creek Valley. Perhaps the most interesting occurrence of this mineral with corundum is that found on Mr. D. M. Hampton's land near Daybook, Yancey County, North Carolina. The staurolite occurs in crystalline aggregates, but more generally as an intimate associate with magnetite, menaccanite, and corundum. There is also considerable chlorite developed between the grains of these minerals. As a constituent of this aggregate, the staurolite is in very small transparent grains of a red brown color (see p. 259).

That from Corundum Hill has been analyzed by Dr. Genth[28] (I), and that from the Hampton place by Dr. Pratt[29] (II and III), with the following results:

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[28] Am. Phil. Soc., Vol. XIII, 1873, p. 381.

[29] Am. J. Soc., 4th ser., Vol. XLVII, 1894, p. 85.

Analyses of staurolite from Macon and Yancey Counties.

	I.	II.	III.
SiO_2	27.91	27.80	27.65
Al_2O_3	52.92	53.09	53.30
Fe_2O_3	6.87	4.81	4.81
FeO	7.80	9.70	9.68
MnO	Trace.	.27	.38
MgO	3.28	2.64	2.65
H_2O	1.59	1.99	1.96
	100.37	100.30	100.43

THE ZEOLITES.

39. *Wellsite, a new mineral.*[30]

Occurrence.—This mineral occurs at the Buck Creek (Cullakeenee) corundum mine in Clay County, and has been found in but one of the numerous veins of this mine. The vein in which the mineral is found is composed chiefly of a plagioclase feldspar and hornblende.

The mineral is found in isolated crystals, mostly attached to the feldspar but also to hornblende and corundum, and is intimately associated with chabazite (see p. 309), which occurs in small, transparent rhombohedrons. The largest crystals that were observed were not over 1 mm. in diameter and 2 mm. in length.

Crystalline form.—The crystals belong to the monoclinic system and they are twinned similarly to those of harmotome and phillipsite. The common habit is shown in fig. 1, which represents a combination of twinning about *c* (001) and *e* (011). The crystals are practically square prisms, terminated by pyramidal faces, and thus imitating closely a simple combination of a prism of one order and a pyramid of the other in the tetragonal system. The apparent prismatic faces are formed for the most part by the pinacoid faces, *b*, but the crystals interpenetrate each other somewhat irregularly so that portions of the base *c* (001) coincide with *b* (see fig. 29). The lines of twinning on the pinacoid faces between *b* and *b* twinned are generally regular, while those between *b* and *c* and also those which cross the prism faces *m* (110) (the apparent pyramid) are generally very irregular. The *b* faces do not show striations parallel to the edges *b* and *m*, which, meeting along the twinning lines, often reveal the complex nature of such crystals; nor were any reëntrant angles observed parallel to the edges of the apparent prism such as are common in phillipsite and harmotome.

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[30] Am. Jour. Sci., 4th ser., Vol. III, 1897, p. 443, and Elisha Mitchell Sci. Soc., Vol. XIV, Pt. II, 1898, p. 62.

Fig. 30 represents another habit of the crystals where *m* (110) is wanting and *a* (100) is in combination with *b* (010). The method of twinning is similar to that already described, but the crystals being terminated by *a* (100) instead of *m* (110) show prominent reëntrant angles at their ends. These crystals are very similar to those of harmotome from Bowling, near Dumbarton on the Clyde, described by Lacroix.

The only forms that were observed were *a* (100), *b* (010), *c* (001) and *m* (110), with *e* (011) only as twinning plane. The faces of the crystals are somewhat rounded and vicinal, so that the reflections were not perfect. The angle of the apparent prism b/\b twinned is approximately 90°. Also the angle m/\m over the twinning plane (011) could be measured only approximately, varying from 0° 49′ to 1° 25′. The appropriate angles are given below, and from those marked with an asterisk the following axial ratio was calculated:

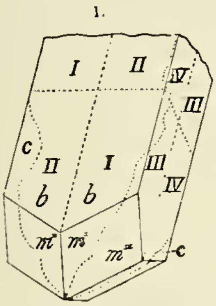

Fig. 29.—Crystals of wellsite from Buck Creek, Clay County, N. C.

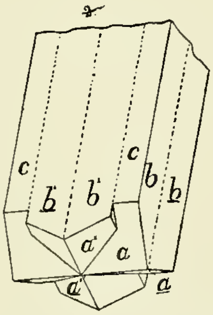

Fig. 30.—Crystals of wellsite from Buck Creek, Clay County, N. C.

$\grave{a} : \bar{b} : \acute{c}$: $.768 : 1 : 1.245 : \beta = 53° 27' = 001 \wedge 100.$

	Measured.	Calculated.
b/\b, 010/\010	*90° (over twinning plane)	
a/\a, 100/\100	*73° 6′ (over twinning plane)	
b/\m, 010/\110	*58° 19′	
c/\a, 001/\100	53° 27′ = β	
c/\m, 001/\110	60°, 59° 45′, 59° 57′	59° 33′

Physical properties.—The crystals are brittle and show no apparent cleavage. The luster is vitreous. Many of the crystals are colorless and transparent while others are white. The hardness is between 4 and 4.5. The specific gravity taken on a number of separate crystals by means of the heavy solution, varied between 2.278 and 2.36. This variation was probably due to the difference in the ratio of the barium to the calcium in the different crystals.

A section parallel to the pinacoid faces *b* (010), the apparent prism, revealed in polarized light the structure shown in fig. 31. The parts I and I extinguish simultaneously, as also II and II, while portions III, which are parallel to the basal plane, show parallel extinction. The section showed something like zonal structure, so that the extinction could be measured only approximately. By using the Bertrand ocular, this was found to be 33° from one pinacoid on to the other over the twinning plane. The axis *a* makes an angle of 52° with the vertical axis ć in the obtuse angle.

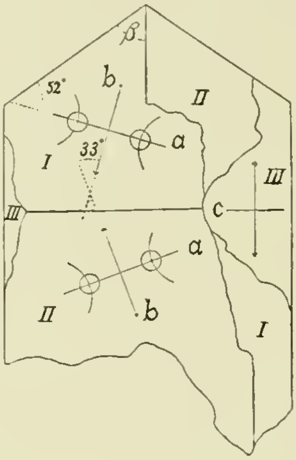

FIG. 31.—Pinacoidal section of wellsite seen in polarized light.

The double refraction is positive and weak. The acute bisectrix c is at right angles to the pinacoid 010, and the divergence of the optical axes is large. 2E probably varies from 120° to 130°, but this could not be measured directly.

Chemical analysis.—The mineral was purified for analysis by means of the heavy solution and that which was used varied in specific gravity from 2.278 to 2.360.

The analyses were made by Dr. H. W. Foote,[31] with the following results:

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[31] Dr. H. W. Foote, of the Sheffield Laboratory, Yale Univ.

Analyses of wellsite from Buck Creek mine, Clay County.

	I.	II.	Average.	Ratio.	
SiO_2	43.62	44.11	43.86	.731 = 3.00	
Al_2O_3	25.04	24.89	24.96	.244 = 1.00	
BaO	5.00	5.15	5.07	.033	.228 = .93
SrO	1.12	1.18	1.15	.011	
CaO	5.76	5.84	5.80	.104	
MgO	0.61	0.62	0.62	.015	
K_2O	....	3.40	3.40	.036	
Na_2O	....	1.80	1.80	.029	
H_2O	13.32	13.39	13.35	.742 = 3.04	
			100.01		

The ratio of $SiO_2 : Al_2O_3 : RO : H_2O$ is very close to 3 : 1 : 1 : 3, which gives the formula $R''Al_2Si_3O_{10}.3H_2O$. The ratio of BaO : CaO : $K_2O + Na_2O$ in the above analysis is nearly 1 : 3 : 2, and the theoretical composition calculated for this ratio is given below, together with the analysis after substituting for Na_2O its equivalent of K_2O and for MgO and SrO their equivalents respectively of CaO and BaO and then recalculating to 100 per cent.

Theoretical composition of wellsite.

	Theory for $R''Al_2Si_3O_{10}.3H_2O$ where R is 1/7Ba, 3/7Ca, 3/7K.	
SiO_2	43.12	42.87
Al_2O_3	24.54	24.27
BaO	6.65	6.62
CaO	6.59	7.27
K_2O	5.98	6.10
H_2O	13.12	12.87
	100.00	100.00

Experiments were made to determine at what temperature the water was driven off, and the results are given in the following table, the mineral being heated in each case until the weight became constant. The last trace of water could be driven off only by heating the mineral over the blast lamp.

Water loss of wellsite at specified temperatures.

	Loss.	
At 100° C.	Nothing.	
125 "	1.93	4.33
175 "	1.48	
200 "	0.92	
260 "	2.45	3.69
295 "	1.24	
Red heat	4.96	5.29
Over blast lamp	0.33	
Total	13.31	

As is seen from the above, about one-third of the water, or one molecule, is given off between 100° and 200°, another third approximately between 200° and 300°, while the remainder is expelled only at an intense heat. This would indicate that the water exists in three different conditions in the molecule. If only that which is expelled below 200° be regarded as water of crystallization, the composition would be $H_4R''Al_2Si_3O_{12} + H_2O$.

This mineral is closely related to the phillipsite group of the zeolites, and this relation is very satisfactorily brought out by a comparison of the crystallographic properties and chemical composition. They have all very nearly the same axial ratios.

Axial ratios of zeolites.

	$\breve{a}$	$: \bar{b} :$	c	
Wellsite	.768	:1:	1.245	$\beta = 53^\circ\ 27'$
Phillipsite	.70949	:1:	1.2563	$\beta = 55\ \ 37$
Harmotome	.70315	:1:	1.2310	$\beta = 55\ \ 10$
Stilbite	.76227	:1:	1.19401	$\beta = 50\ \ 49\frac{3}{4}$

In their habit and methods of twinning, they are also very similar, all the crystals being uniformly penetration twins. This is especially noticeable between the new mineral and phillipsite and harmotome, which are common as double twins with *c* (001) and *e* (011) as twinning planes.

The place of the mineral in the phillipsite group is clearly shown by a comparison of chemical compositions. Arranged in order of their proportions of silica and water to the bases, we have the following interesting series, in which R represents the bivalent elements:

Wellsite	$RAl_2Si_3O_{10} . 3H_2O$
Phillipsite	$RAl_2Si_4O_{12} . 4\frac{1}{2}H_2O$
Harmotome	$RAl_2Si_5O_{14} . 5H_2O$
Stilbite	$RAl_2Si_6O_{16} . 6H_2O$

The ratio of $RO : Al_2O_3$ is constant, 1 : 1, in the series while the proportion of silica and water have a constant ratio, 1 : 1, between themselves, except in the case of phillipsite. As there is, however, considerable variation in the analyses of phillipsite, it is not improbable that the ratio of $SiO_2 : H_2O$, given as $4 : 4\frac{1}{2}$, should be in some cases at least 4 : 4. The minerals then form a gradual series, increasing in the proportions of SiO_2 and H_2O from wellsite to stilbite.

Fresenius[32] has shown that this group of minerals may be regarded as a series in which the ratio of $RO : Al_2O_3$ is constant, 1 : 1, while the silica and water vary between certain limits. He has assumed as these two limits:

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[32] Zs. Kr., Vol. III, 1878, p. 42.

$$RAl_2Si_6O_{16} + 6H_2O \text{ and}$$
$$R_2Al_4Si_4O_{16} + 6H_2O$$

The first would be a hydrated calcium albite and the last a hydrated anorthite. From a comparison of the wellsite-stilbite series, it seems more probable that the anorthite end would be $RAl_2Si_2O_8 + 2H_2O$, or doubling this for better comparison with the formula of Fresenius, $R_2Al_4Si_4O_{16} + 4H_2O$.

It is not unreasonable to expect that the first or anorthite member of this series may be found in nature and the completed series would then be:

Anorthite limit	$RAl_2Si_2O_8 + 2H_2O$ (not yet identified)
Wellsite	$RAl_2Si_3O_{10} + 3H_2O$
Phillipsite	$RAl_2Si_4O_{12} + 4\frac{1}{2}H_2O$ (perhaps $4H_2O$)
Harmotome	$RAl_2Si_5O_{14} + 5H_2O$
Stilbite	$RAl_2Si_6O_{16} + 6H_2O$

It is also interesting to note that the formula of the new mineral wellsite is the same as that assigned to adingtonite,[33] but the latter is essentially a barium mineral and being tetragonal shows no crystallographic relations to wellsite.

Pyrognostics.—When heated before the blowpipe, the mineral exfoliates slightly and fuses at 2.5-3 to a white bead, coloring the flame slightly yellow. In the closed tube water is given off at a low temperature. It is very readily decomposed by hot hydrochloric acid with the separation of silica, but without gelatinization. When the water in the mineral is driven off below 265° C., it is nearly all regained on exposing the mineral to the air. If the water, however, is driven off at a red heat, none is regained by the mineral.

Name.—The name wellsite was given to this mineral in honor of Prof. H. L. Wells, of the Sheffield Scientific School, Yale University.

40. Chabazite.[34]

As described on page 304, this mineral is intimately associated with the wellsite at the Buck Creek (Cullakeenee) corundum mine in Clay County, occurring as a mass of small crystals coating the feldspar, hornblende, and corundum. Thus far this mineral has been found only at the large open cut on the east side of Buck Creek, just northwest of the shaft.

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[33] Dana Mineralogy, 6th edition, 1902.

[34] Elisha Mitchell Sci. Soc., Vol. XIV, Pt. II, 1898, p. 70.

The crystals are transparent to white and very small, no crystals being found that measured over one millimeter in diameter.

The only form observed on any of these crystals was the unit rhombohedron, $10\bar{1}1$, which occurs as simple crystals and also as penetration-twins, with *c* as the twinning axis.

Material for analysis was obtained by means of the heavy solution, and, as had been observed by preliminary experience on the crystals of chabazite, the specific gravity varies considerably.

The mineral was analyzed by Dr. Baskerville with the following results:

Analyses of chabazite from Buck Creek mine, Clay County.

	I.	Ratio.		II.	Ratio.	
SiO_2	45.08	.751 = 3.79		46.15	.769 = 3.79	
Al_2O_3	19.68	.193 = 1.00		20.74	.203 = 1.00	
FeO	2.00	.028	.163 = .84	2.00	.028	.158 = .77
CaO	7.22	.129		6.92	.124	
BaO	0.18	.001		0.24	.001	
MgO	0.23	.005		0.22	.005	
K_2O	4.34	.046	.100 = .50	4.10	.043	.097 = .47
Na_2O	3.35	.054		3.35	.054	
H_2O	18.00	1.000 = 5.02		16.30	.905 = 4.46	
	100.08			100.02		
Specific gravity	2.147—2.203			2.203—2.244		

The ratio of $Al_2O_3 : SiO_2 : H_2O$ is near to 1:4:5: and Al_2O_3: $(R''.K_2.Na_2)O$ is close to 4:5.

Usually in the composition of the chabazites the ratio of Al_2O_3: $(Ca.K_2Na_2)O$ is near to 1:1. In the present analysis, no attempt was made to separate any strontium present from the calcium. As a small amount of this element would cause considerable variation in the per cent of CaO, this would readily account for the excess of this oxide in the analysis.

The composition of chabazite has always been somewhat uncertain, as there is often a wide variation in the analyses of specimens from the same locality. The hypothesis advanced by Strong,[35] that chabazite is an isomorphous mixture of

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[35] Ber. Oberhess. Ges., Vol. XVI, 1897, p. 74; and Dana Mineralogy, 6th edition, 1892, p. 591.

$$m.\ (CaNa_2)Al_2Si_2O_8 + 4H_2O$$
$$n.\ (CaNa_2)Al_2Si_6O_{16} + 8H_2O,$$

explains satisfactorily the variations observed in this mineral. This is analogous to the composition of albite-anorthite feldspars.

The approximate ratios deduced from the above analysis, of $SiO_2 : Al_2O_3 : (Ca.Na_2)O : H_2O = 4:1:1:5$, would give for the formula of this chabazite $m:n = 1:1$, but with a low amount of water.

The variation in composition and the high specific gravity of the mineral are without doubt due to the varying proportions of barium and strontium in the molecule.

The occurrence of chabazite at Buck Creek is interesting, as this is the only known locality at which this mineral is found in North Carolina.

These last two minerals, wellsite and chabazite, are the only two zeolites that have been found associated with corundum, and they have been observed but at one locality. They are secondary minerals and have been derived from the feldspar with which they are associated, and perhaps in part the corundum may have aided in their formation to the extent of a part of the alumina. It is, however, the feldspar that has furnished the lime, CaO, and the soda, Na_2O. As both these zeolites contain barium oxide, it was thought that the feldspar which was undoubtedly the source of this oxide would contain sufficient of it to be classified as a barium feldspar; but an analysis made of this showed no more than a trace of barium oxide. This, however, would be enough to account for the barium observed in the zeolites, as it has been found in them in but very small quantity.

The results of the analysis of this feldspar are given below:

Analysis of feldspar of zeolites from Buck Creek mine, Clay County.[36]

SiO_2	54.75
Al_2O_3	26.87
FeO	0.89
CaO	9.30
BaO	Trace.
MgO	0.54
Na_2O	5.79
K_2O	0.82
H_2O	1.15
	100.12

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[36] By Dr. Charles Baskerville.

The water obtained in the above analysis indicates that the mineral had suffered some kaolinization. From the percentage of lime (CaO) and soda (Na_2O), the feldspar is seen to belong to the andesine variety of the plagioclase feldspars. For description of these feldspars see page 77.

THE MICAS.

The minerals classified in this division are divided into the following groups: (I) The mica group, including the micas proper, characterized by the elasticity of the laminæ; (II) the clintonite group or the brittle micas; (III) the chlorite group, characterized by the toughness and the inelasticity of the laminæ; (IV) a supplementary group, the vermiculites, resulting chiefly from the alteration of some one of the minerals of the other groups.

These minerals all have a characteristic micaceous structure and a perfect basal cleavage, which enables them to be separated into very thin lamellæ. In crystal form they are all very similar, belonging to the monoclinic system; but the plain angles of the base being 60° or 120° the crystals closely approximate hexagonal or orthorhombic symmetry. They all yield water upon ignition, the chlorites containing the highest ratio (10 to 15 per cent), except some of the minerals in the supplementary group of the vermiculites.

MICA GROUP.

Of this group, but two species have been identified as associated with the corundum in North Carolina:

Muscovite, potassium mica, $(H,K)AlSiO_4$.

Biotite, magnesium-iron mica, $(H,K)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$ in part. They are both characterized by perfect basal cleavage, which permits their separation into very thin laminæ that are tough and elastic, some specimens exhibiting this elasticity more than others.

41. Muscovite.

This species is divided into three varieties:

41. Ordinary muscovite.—This is often in crystals and in large tabular blocks. The folia are usually very elastic, the thin laminæ springing back very forcibly when bent, and they have a decidedly vitreous luster.

41a. Damourite.—This variety includes margarodite, gilberite, hydromuscovite, and most of the hydro-micas. The folia are usually in small scales, are less elastic than the ordinary muscovite and the luster is somewhat pearly.

41b. Fuchsite or chrome-mica.—This is characterized by its green color due to the presence of chromium sesquioxide.

The hardness of the muscovites varies from 2 to 2.5. In color they vary from colorless, gray, brownish to green of fuchsite. When thin, the cleavage plates of mica are transparent, while the thicker crystals are nearly or quite opaque, due to the absorption of the light rays normal to the cleavage plane; but the transverse rays being less absorbed, the crystals are translucent when viewed through the prism.

Ordinary muscovite is not commonly associated with corundum, except where the corundum occurs in a pegmatite vein, in gneiss or schist. At the Presley mine, in Haywood County, corundum is found in muscovite crystals, with a diameter from 1 to 4 inches (see B of Pl. XXIX). The line of separation between the two minerals is very sharp and distinct, as is also the crystal outline of the corundum, and it does not seem probable that the muscovite is an alteration product of the corundum. On the basal surface of the corundum there is a coating of the damourite variety of muscovite, which is apparently an alteration product of the corundum.

The muscovite damourite is somewhat commonly associated with corundum and is sometimes the result of its alteration. When first described this mineral was supposed to be a distinct species, but later was shown by Dr. Genth to belong to muscovite. It varies from small or fine scales to a fibrous and compact mineral with a silky luster.

The principal corundum localities where this muscovite is found are at Crowders and Chubbs mountains, Gaston County, where it occurs in scales, surrounding the crystals and masses of corundum, and is usually stained with ferric oxide; at Sapphire, Jackson County, at the Sapphire mine, nodules and crystals of pink, white, and blue corundum are surrounded by a mass of small scales of this mica, usually mixed with some margarite, and sometimes with a little chlorite; at the Presley mine, Haywood County, the muscovite occurs as small scales surrounding the corundum and also as a compact or fibrous coating enveloping the crystals of corundum.

At this last locality this mica has apparently been formed by the alteration of the corundum, as it has also been observed in minute scales on the basal surfaces of many corundums.

At Cullasaja, Macon County, at the Corundum Hill mine, a mica-schist occurs in contact with the peridotite outcrop, which Dr. Genth[37] has shown to be a muscovite (damourite)-schist. In this he had found a few crystals of corundum.

At the Egypt mine, Yancey County, corundum has been found which has begun to alter to muscovite in the interior as illustrated in A of Plate XXX.

Fuchsite or chrome mica has been identified at only one locality, the Hayes (Egypt) mine, Yancey County, and this occurrence is at the present time the only one known in this State. It is in very fine scales enclosing small particles of chrysolite.

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[37] Am. Phil. Soc., Vol. XIII, 1893, p. 384.

42. Biotite (magnesium-iron mica).

This mica is generally readily distinguished from the others by its color and luster. The color is green-black to black and deep black in the thick crystals. The laminæ, when thin enough to transmit light, are greenish to brown-red to brown; rarely are the thin laminæ colorless. The luster is splendent, inclined to a more or less pearly and in the deep black biotites the luster is often submetallic. The hardness, 2.5 to 3, is a little greater than the muscovites. The basal cleavage is perfect.

No crystals of biotite have been observed at any of the corundum localities, the mineral occurring in masses usually with garnet and corundum, or corundum alone. As a vein material, it occurs as a mass of small plates resembling a coarse biotite schist.

This mineral occurs very abundantly at the Bad Creek mine, Sapphire, Jackson County (see description of this vein on p. 254). The biotite-schist is sometimes filled with corundum crystals up to an inch in diameter, while at other parts there is an entire absence of corundum in the biotite and then the laminæ are very much broader. Apatite crystals three-fourths inch in diameter are also abundant in the biotite. The corundum surrounded by biotite is illustrated in B of Plate XXX.

CLINTONITE GROUP.

The minerals of this group are similar to the micas in cleavage and crystalline form, but are usually readily distinguished from them physically by the brittleness of the laminæ and chemically by being more basic in their character than the micas.

Two species of this group are found associated with corundum:

Margarite, $H_2CaAl_4Si_2O_{12}$, a basic silicate of aluminum and calcium.

Chloritoid, $H_2(Fe,Mg)Al_2SiO_7$, a basic silicate of aluminum and ferrous iron with magnesia.

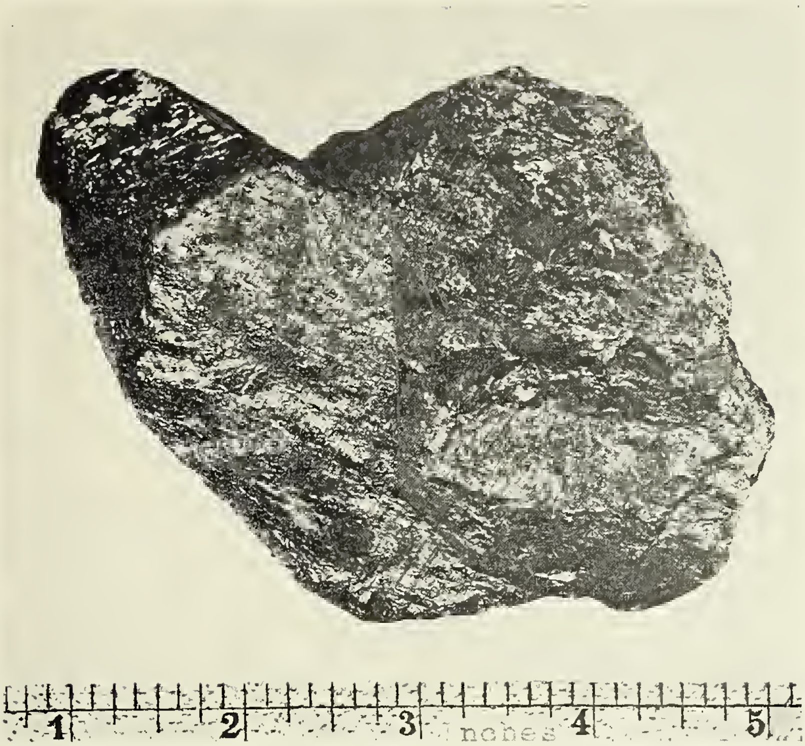
These minerals form something like a transitional series between the micas and chlorites.

43. Margarite.

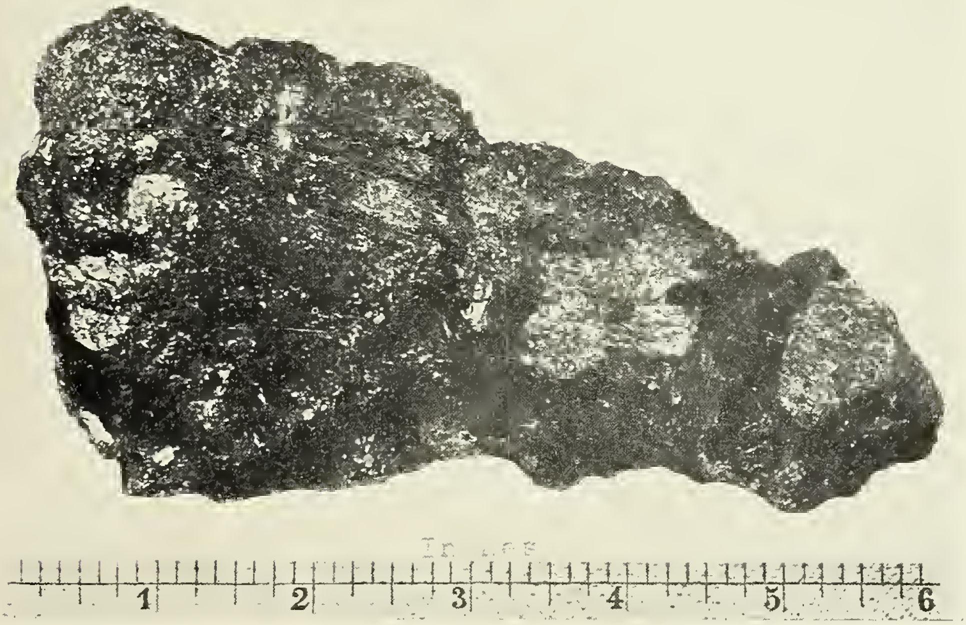
This mineral is one of the most important of those associated with corundum or emery, and this is almost the only mode of occurrence of margarite that is known. By this knowledge of its occurrence with corundum a number of corundum and emery deposits have been discovered.

This species was first known from the corundum locality of Mount Greiner, Steizing, in Tyrol, and its importance in its relation to corundum and emery was revealed by its occurrence at the emery mines in Asia Minor and at the corundum localities of Pennsylvania and North Carolina.

It is rarely in distinct crystals, and these are usually tabular, parallel to the basal planes. It has a perfect basal cleavage, the laminæ being rather brittle. The luster of the basal plane is pearly. The color is white, pink and yellowish and greenish white. Its prevailing color, however, when it is in crystals or in laminæ, is a pink or pinkish white. Its hardness is between 3.5 and 4.5.



A, MOTTLED AND BANDED BLUE AND WHITE CORUNDUM ALTERING TO MUSCOVITE IN INTERIOR, HAYES (EGYPT) MINE, YANCEY COUNTY, N. C.



B, CORUNDUM IN BIOTITE, BAD CREEK MINE, SAPPHIRE, JACKSON COUNTY, N. C.

Margarite has been found at many of the corundum mines in this State, and it may be that at all the peridotite corundum mines there is at least a little of it, but at the most it is in very small amount. At two localities, however, the Buck Creek mine and the Bad Creek mine, margarite is very abundant and in beautiful varieties. At the Buck Creek mine it occurs in groups of laminated crystals, some of which Genth[38] has described as being 2 inches long, $1\frac{1}{2}$ inches wide, and five-eighths inch thick. The color on the basal cleavage surface is a faint pinkish white, while the prism faces are darker. "Tourmaline is sometimes enclosed between the laminæ." At both these localities feldspar is very common and the margarite has been found more abundantly where the corundum is associated with feldspar. For analysis of this margarite see I, below.

Another variety, which is the commonest occurrence, and is intimately associated with zoisite and a white to grayish white corundum, is in the form of broad laminæ of a delicate pink color. It has been analyzed (II, below) by Dr. Genth.

Still another variety has been described by Dr. Genth of a grayish green color, that occurs in thin seams which are an aggregate of minute pearly scales (see analysis III, below).

In Iredell County, as at Belts Bridge, margarite is frequently found with the corundum, which it surrounds as a compact casing (analysis IV, below) as is shown in fig. 27.

Analyses of margarite from Clay and Iredell Counties.

	I. Buck Creek.[39]	II. Buck Creek.[40]	III. Buck Creek.[41]	IV. Belts Bridge.[42]
SiO_2	29.34	30.72	29.63	33.10
Al_2O_3	48.73	49.83	51.19	52.20
Cr_2O_3	....	....	0.13	....
FeO	0.78	0.84	0.59	Trace.
MgO	0.78	0.76	1.09	....
CaO	11.32	10.84	11.28	8.44
Li_2O	Trace.	Trace.	...	...
Na_2O	2.61	2.19	1.22	2.59
K_2O	0.10	0.26	0.20	....
Loss on ignition	6.55	6.21	4.73	4.85
	100.21	101.65	100.06	101.18
Specific gravity	2.990	3.055	3.064	

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[38] Am. Phil. Soc., Vol. XIII, 1873, p. 399.
[39] Chatard, Am. Phil. Soc., Vol. XIII, 1873, p. 401.
[40] Genth, ibid., p. 400.
[41] Ibid.
[42] Julian, Bull. U. S. Geol. Survey No. 74, p. 69.

At the Bad Creek mine the margarite occurs in broad foliated plates of a pink color, more or less mixed with chlorite. There is usually considerable corundum in small grains, particles, and lumps enclosed by the micas.

Another variety is in the form of a margarite-chlorite-schist, carrying a small amount of garnet and corundum. The laminæ in the schist are not so broad as in the variety first described, but are of the same pink color. This schistosity developed in the margarite and chlorite is evidence of a considerable amount of shearing.

Still another variety, which has the same pink color as the other two, is in appearance like a compact margarite but is made up of very fine scales of the mineral.

At these two localities the margarite is one of the principal and most abundant associated minerals and is evidently an alteration product dependent upon the corundum.

At Hogsed farm, near Elf, Clay County, remnants of rhombohedral corundum have been found that are encased with secondary massive margarite (see A of Pl. XXXI).

At the Corundum Hill mine, Macon County, Dr. Genth[43] reports the occurrence of margarite in a rock consisting "of a feldspathic mineral mostly decomposed into kaolinite, a greenish hornblende, and small quantities of a chloritic mineral, the whole mass intermixed with white and pink corundum and laminæ of margarite." It is, however, a very rare mineral at this mine.

The margarite when purified is white and has a pearly luster. It has been analyzed by Dr. Genth[44] (I) and Mr. Chatard[45] (II) as follows:

Analyses of margarite from Corundum Hill mine.

	I.	II.
SiO_2	28.11	28.80
Al_2O_3	49.16	49.57
FeO	0.43	0.34
MgO	0.45	0.75
CaO	11.08	11.33
Li_2O	0.45	....
Na_2O	0.67	....
K_2O	0.22	....
Loss on ignition	6.43	6.64
Residue (corundum)	3.31	....
	100.31	
Specific gravity	3.087	

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[43] Am. Phil. Soc., Vol. XIII, 1873, p. 398.

[44] Ibid., p. 400.

[45] Ibid., p. 400.

44. Chloritoid.

The occurrence of this mineral associated with the North Carolina corundum is very rare. A single small crystal of chloritoid has been described by Dr. Genth from the Cullasaja corundum mine, which was found in the washing of the alluvial deposits.

In the pyrophyllite slates of Chatham County it occurs in dark blackish-green shining scales disseminated through the white rock. This has been analyzed by Dr. Genth[46] with the following results:

Analysis of chloritoid from Corundum Hill mine.

SiO_2	26.13
Al_2O_3	40.11
Fe_2O_3	3.44
FeO	23.01
MnO	Trace.
MgO	0.94
Loss on ignition	6.91
	100.54
Specific gravity	3.353

CHLORITE GROUP.

A large part of the minerals of this group are characterized by the green color which is common in most of the silicates in which ferrous iron is prominent. This species is closely allied to the micas in its crystallographic properties, crystallizing in the monoclinic system and having perfect basal cleavage. They can, however, usually be distinguished from the micas by the toughness and inelasticity of the laminæ.

The chlorites are very closely related among themselves and it is often extremely difficult to draw strict lines between them. They are for the most part silicates of aluminum with ferrous iron and magnesium and chemically combined water. The alumina is often replaced in small part by ferric iron, and very rarely by chromic oxide, which when present imparts a pinkish color to the chlorites. Ferrous iron is sometimes replaced by manganese. Calcium and alkalies that are usually present in all the true micas, are either absent or present in but small amount.

The chlorites are often the result of the alteration of other species and, as was described on page 123, most of the chlorite found associated with the corundum in North Carolina is the result of the alteration of the peridotite influenced by the corundum. It is also often the result of the alteration of the mineral species, pyroxene, amphibole, garnet, biotite, etc. A chlorite derived in part from the alteration of chromite is described on page 75.

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[46] Am. Phil. Soc., Vol. XIII, 1873, p. 397.

45. Prochlorite.

The most common of the chlorites found associated with corundum is prochlorite. It is often in six-sided prisms or tables, whose sides are strongly furrowed and dull. It also occurs in aggregates of broad dark-green laminæ and others in which the laminæ are very finely divided. Its hardness is 1 to 2 and its specific gravity 2.78 to 2.96.

At the Corundum Hill and Buck Creek corundum mines the best crystals have been found. At the latter locality crystals were observed that were 20 mm. by 15 mm. See B of Pl. XXI.

Most of the chlorite found in a corundum vein is the prochlorite, and much of the mineral formerly called ripidolite is also the same mineral. The prochlorite associated with the corundum differs from the ordinary prochlorite in the small amount of ferrous iron present in the mineral. As would be expected from its mode of formation—the alteration of a peridotite low in iron influenced by corundum—the ferrous iron in the prochlorite is largely replaced by magnesia. The broadly foliated varieties from the Corundum Hill mine have been analyzed by Dr. Genth[47] and Chatard,[48] I and II, below, respectively:

Analyses of prochlorite from Corundum Hill mine, Macon County.

	I.	II.
SiO_2	27.56	27.17
Al_2O_3	22.75	22.35
Fe_2O_3	2.56	2.71
FeO	5.43	5.43
(NiCo)O MnO	0.30	0.26
MgO	28.47	27.73
Ignition	13.80	14.36
	100.87	100.01

As is seen from the above analyses the per cent of the ferrous oxide is very low and that of the magnesia is correspondingly high and this will be found to be true of nearly all the prochlorite associated with corundum.

46. Clinochlore (formerly ripidolite).

46a. Penninite.—The penninite variety of this chlorite has been identified at many of the peridotite formations at which there is a scarcity of corundum. At the Ray chrome mine, near Burnsville, Yancey County, the penninite occurs in well-defined crystals that are imbedded in talc.

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[47] Am. Phil. Soc., Vol. XIII, 1873, p. 393.

[48] Ibid.

46b. Kämmererite.—At the same locality is found the chrome penninite, kammererite, in violet and peach-blossom red scales and also rarely in three and six-sided plates. Other localities where kammererite is found are the Corundum Hill mine, Macon County; Webster, Jackson County; and Rich Mountain, Watauga County. Scales of this mineral are sometimes found within a mass of chromite and have undoubtedly been formed by the alteration of minute films of magnesian silicates enclosed by the chromite, the latter being acted upon to the very slightest degree, yet sufficient to furnish the requisite amount of chromic oxide.

The chlorite, corundophilite, so commonly associated with emery, has not been definitely identified in North Carolina.

VERMICULITES (47-52).

This supplementary group of the micas includes a number of micaceous minerals which are hydrated silicates varying somewhat widely in composition and being in part closely related to the chlorites. They are alteration products of some of the micas and chlorites, and have usually retained the characteristic micaceous cleavage. The laminæ are generally soft, pliable. and inelastic with a pearly or bronze-like luster. The color varies from white to yellowish and brown. The common characteristics of all the vermiculites is the property of exfoliation; opening out into long worm-like threads when heated. Some show this exfoliation to a much greater degree than others.

The vermiculites are of a more or less indefinite chemical composition and vary widely in their composition according to the original mineral from which they are derived and the degree of the alteration. A chemical analysis is nearly always necessary to identify the different varieties, for as the variety depends on the degree of the alteration, different portions of the same specimen often show two varieties of vermiculite.

Dr. Genth[49] in his paper on "Corundum, its alteration and associated minerals," describes a number of vermiculites that he identified from North Carolina, but they cannot be identified without a special analysis and it would be difficult even then to isolate some of the particular vermiculites.

The following have been described from North Carolina:

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[49] Am. Phil. Soc., Vol. XIII, 1873, p. 359.

47. *Jefferisite or culsageeite.*

This mineral occurs at the Corundum Hill mine in foliated masses of yellowish-brown color and also in greenish, brownish yellow scales, not over one-eighth of an inch in diameter. The first has been analyzed by Mr. Koenig[50] and the second by Mr. Chatard:[51]

Analyses of jefferisite or culsageeite from Corundum Hill mine, Macon County.

	I.	II.
SiO_2	33.93	34.00
Al_2O_3	17.38	20.36
Fe_2O_3	5.42	4.91
FeO	0.50	0.42
NiO	0.35	0.57
MgO	23.43	21.71
Ignition	19.17	18.50
	100.18	100.47

48. *Kerrite.*

This variety, as described by Genth, consists of innumerable fine scales of a pale greenish-yellow color and of a pearly luster and was found at the Corundum Hill mine, Macon County.

The analysis by Mr. Chatard[52] follows.

Analysis of kerrite from Corundum Hill mine, Macon County.

SiO_2	38.31
Al_2O_3	11.41
Fe_2O_3	1.93
FeO	0.32
(NiCo)O	0.29
MgO	26.30
Ignition	21.22
	99.78
Specific gravity	2.303

49. *Maconite.*

This variety was identified at the Corundum Hill mine by Genth, who describes it as a dark-brown scaly mineral with pearly luster inclining to sub-metallic. It closely resembles the scaly jefferisite.

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[50] Am. Phil. Soc., Vol. XIII, 1873, p. 390.

[51] Ibid.

[52] Ibid., p. 394.

The mean result of two analyses by Chatard[53] are given below.

Analysis of maconite from Corundum Hill mine, Macon County.

SiO_2	34.22
Al_2O_3	21.53
Fe_2O_3	12.41
FeO	0.32
NiO	0.12
MgO	14.46
Li_2O	Trace.
Na_2O	0.51
K_2O	5.70
H_2O	11.85
	101.12
Specific gravity	2.827

50. *Lucasite.*

This, another mineral similar to jefferisite, was identified by Mr. Chatard at the Corundum Hill mine. It is yellowish brown in color and made up of small laminæ not over 2 mm. in diameter. The basal cleavage is eminent and the luster sub-metallic to greasy. It is found associated with grass-green actinolite.

The analysis of this vermiculite by Mr. Chatard[54] is as follows:

Analysis of lucasite from Corundum Hill mine, Macon County.

H_2O at 110° C.	3.78
H_2O at red heat	6.98
SiO_2	31.81
Al_2O_3	12.99
Cr_2O_3	0.54
Fe_2O_3	5.29
FeO	0.11
MnO	0.05
MgO	24.83
CaO	0.14
Na_2O	0.20
K_2O	5.76
	100.48

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[53] Am. Phil. Soc., Vol. XIII, 1873, p. 395.
[54] Bull. U. S. Geol. Survey No. 74, p. 66.

51. *Willcoxite.*

This vermiculite occurs in greenish white scales of a pearly luster, somewhat resembling talc. It has been identified at Shooting Creek and the Buck Creek mine, in Clay County; and at the Corundum Hill mine, Macon County. It has been found surrounding corundum and is probably the result of the alteration of that mineral. It is one of the easier of the vermiculites to identify in the field.

Analyses of this mineral from the two localities in Clay County have been made by Mr. Koenig[55] and the results are given below:

Analyses of willcoxite from Clay County.

	Shooting Creek.	Buck Creek.
SiO_2	28.96	29.50
Al_2O_3	37.49	37.56
Fe_2O_3	1.26	1.40
FeO	2.44	2.38
MgO	17.35	17.20
Li_2O	Trace.	Trace.
Na_2O	6.73	6.24
K_2O	2.46	2.42
H_2O	4.00	3.32
	100.69	100.02

52. *Dudleyite.*

At the Buck Creek mine, Clay County, this vermiculite has been found very sparingly. It has a soft bronze or brownish yellow color; a pearly luster and is probably the result of the alteration of margarite, whose form it still retains. An analysis of this mineral by Dr. Genth[56] gave:

Analysis of dudleyite from Buck Creek mine, Clay County.

SiO_2	32.42
Al_2O_3	28.42
Fe_2O_3	4.99
FeO	1.72
MgO	16.87
Li_2O	0.19
Na_2O	1.52
K_2O	0.56
Loss on ignition	13.43
	100.12

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[55] Am. Phil. Soc., Vol. XIII, 1873, p. 396.

[56] Am. Phil. Soc., Vol. XIII, 1873, p. 402.

Some of the vermiculites are common at all the corundum localities in peridotite, and often in a border vein the corundum-bearing zone is separated from the gneiss by a narrow zone of vermiculites; sometimes they form the principal part of the corundum-bearing zone (see fig. 19, p. 201). Beautiful and perfect crystals of vermiculite pseudomorph after clinochlore are occasionally found at the various peridotite localities. Crystals of clinochlore have also been observed that were only partially altered into vermiculite.

As seen from the above description some of the vermiculites have not been very generally recognized at the different corundum mines, but as a group they are common and often play an important part in locating a corundum vein.

HYDROUS MAGNESIAN SILICATES.

53. *Serpentine.*

Serpentine has been found in crystals only as pseudomorphs, more commonly having the form of chrysolite. Some kinds are pseudomorphs after pyroxene, amphibole, spinel, chondrodite, garnet, etc. Serpentine is usually massive, but is sometimes foliated and is also delicately fibrous; it is also fine granular and amorphous. Various names have been given to serpentine, the name being dependent upon physical structure. A pseudo-cleavage is sometimes very distinct; occasionally prismatic (50°) and again cubical (90°). Its fracture is conchoidal or splintery. It varies rather widely in hardness and in specific gravity, the former being 2.5 to 4 and the latter 2.20 to 2.65. The luster is sub-resinous to greasy, pearly, silky, wax-like, and sometimes earthy; and it usually has a greasy feel. The color is dull and usually some shade of green, as leek-green, blackish green, and oil-green; sometimes reddish and brownish yellow.

Chemically, serpentine is a hydrous magnesium silicate, with the formula, $H_4Mg_3Si_2O_9$. A part of the magnesia, MgO, is often replaced by ferrous oxide, FeO. The water, H_2O, is all chemically combined in the form of hydroxyl and not as water of crystallization.

Serpentine, which is always the result of the alteration of some other mineral, especially chrysolite, is a very common associate of corundum in the peridotite rocks. This alteration of the chrysolite in the peridotites is first observed along the borders of the grains, forming a complete network around the chrysolite grains. The next stage is the formation of the serpentine along the irregular fissures and cleavage cracks through the grains of the chrysolite. As this alteration goes on, the serpentine gradually replaces the chrysolite until there is no trace of the latter left. Sometimes the granular structure of the rock is not changed in this process, but more often the change completely obliterates all the former structure. Nearly all the varieties of serpentine have been observed from the alteration of the peridotites. For further description of this alteration and the formation of serpentine, see page 118. Complete alteration of the peridotites to serpentine, save in a few small areas near French Broad River (see p. 49), is exceptional in North Carolina.

53. Massive serpentine.—This includes all the massive varieties of serpentine, precious serpentine, of a rich oil-green color and translucent even when in thick pieces; common serpentine, when of dark shades of color and sub-translucent; resinous, when of honey-yellow to light oil green colors and a waxy or resin-like luster.

Nothing that could be called a genuine precious serpentine has been found in North Carolina. Small seams, up to one-half an inch thick, of resinous serpentine have been found at the Buck Creek mine, Clay County. Common serpentine is very abundant at all the peridotite localities. A grayish green, massive serpentine from the Corundum Hill mine has been analyzed with the following results:[57]

Analysis of massive serpentine from Corundum Hill mine, Macon County.[58]

SiO_2	41.90
MgO	40.16
H_2O	16.16
NiO	0.10
Fe_2O_3	0.91
Al_2O_3	0.71
	99.94

53a. Williamsite.—This is a variety of serpentine that is somewhat lamellar in structure but graduates into the massive. It is apple-green to brownish green in color, and is without a greasy feel. A serpentine resembling this from Webster has been analyzed by Dr. Genth.[59] The results of the analysis are as follows:

Analysis of williamsite from Webster, Jackson County.

SiO_2	43.87
Al_2O_3	0.31
MgO	38.62
FeO	7.17
MnO	Trace.
NiO	0.27
CaO	0.02
H_2O	9.55
Chromite	0.57
	100.38

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[57] Am. Jour. Sci., 3d ser., Vol. XL, 1890, p. 308.

[58] By E. A. Schneider.

[59] Bull. U. S. Geol. Survey No. 74, p. 63.

53b. Marmolite.—This is the thin foliated variety of serpentine; the folia being brittle and often easily separated. The color is usually greenish white. It has been found in the Webster peridotite and at the Baker mine in Caldwell County.

53c. Chrysotile.—Chrysotile is a delicately fibrous serpentine with a silky luster. The fibers are usually flexible and easily separated. It is this variety that constitutes much of what is called asbestos (see p. 391). In color it is greenish white, green, olive-green, yellow, and brownish. It often forms seams in the massive serpentine. Splendid specimens of this mineral have been found at the Baker mine, and near Patterson in Caldwell County; at the Buck Creek mine, Clay County; also at Webster, Jackson County, and Corundum Hill mine, Macon County. This variety of serpentine is illustrated in fig. 32.

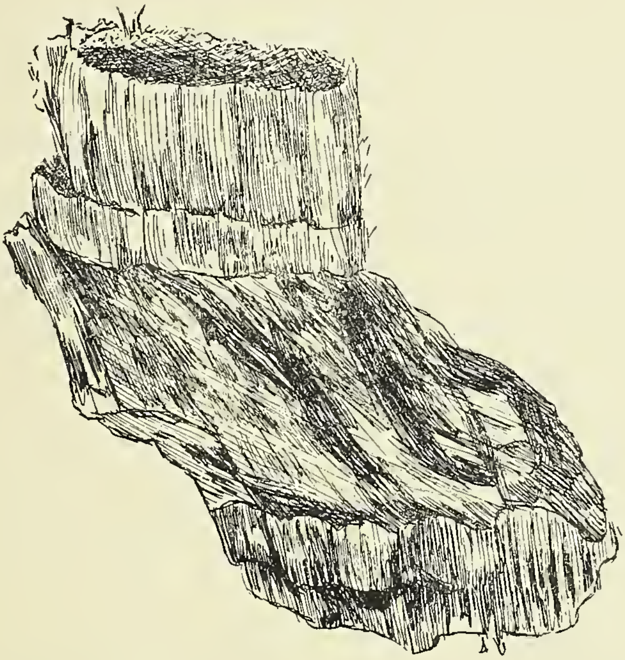

FIG. 32.—Chrysotile, the fibrous variety of serpentine.

53d. Picrolite.—This is somewhat similar to the chrysotile, but is columnar, and the columns or fibers are not easily flexible and usually break with long splintery fracture. Its color is dark green to mountain-green and grayish green. It occurs more or less frequently at many of the peridotite localities. The best has been found at the Baker mine, Caldwell County, and the Buck Creek mine, Clay County.

An analysis of a grayish green variety from the latter locality gave the following results:[60]

Analysis of picrolite from Buck Creek mine, Clay County.[61]

SiO_2	42.94
MgO	36.53
FeO	1.88
NiO	0.61
H_2O	13.21
Fe_2O_3	3.33
Al_2O_3	1.72
	100.22

54. Cerolite.

There are a number of magnesian silicates that are allied to serpentine but are of doubtful character. One of these, cerolite, has been identified by Dr. Genth from the Corundum Hill mine, Macon County. It is in white or yellowish masses in small veins or seams in the decomposed chrysolite. This mineral contains a much larger percentage of silica (SiO_2) and water (H_2O) than serpentine and a correspondingly lower per cent of magnesia (MgO).

55. Deweylite.

This mineral is amorphous and sometimes resembles a brownish or yellow resin. It is very brittle and is often found badly cracked. It is a magnesium silicate near serpentine in composition but contains more water. The formula may be $4MgO . 3SiO_2 . 6H_2O$.

Deweylite occurs at nearly all the peridotite localities and that from the Corundum Hill mine, Macon County, which occurs with the aragonite, has been analyzed by Dr. Baskersville. Its specific gravity was found to be 2.318-2.357. The results of the analysis are as follows:

Analysis of deweylite from Corundum Hill mine, Macon County.

SiO_2	45.51
Al_2O_3	1.26
FeO	2.36
MgO	31.42
CaO	0.40
K_2O	0.33
Na_2O	0.96
H_2O	17.93
	100.17

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[60] Bull. U. S. Geol. Survey No. 74, p. 63.

[61] By E. A. Schneider.

The analyses of deweylite vary widely, even in specimens from the same locality. It is a mineral that has been formed by the alteration of the chrysolite, but is not the direct alteration product. As chrysolite becomes serpentinized, it would on further hydration pass over into deweylite or some of the other allied minerals.

56. *Genthite.*

At a great many of the peridotite localities, genthite occurs as an amorphorous coating or thin seams in the rocks. These seams or veins sometimes reach a thickness of nearly half an inch (see p. 398). The mineral is amorphous with sometimes a delicate hemispherical or stalactitic surface. Its luster is resinous and color pale apple-green to yellowish. In hardness it is from 3 to 4.

Genthite may be considered a deweylite with part of its magnesia replaced by nickel oxide. Its formula to correspond to that of deweylite would be $2NiO.2MgO.3SiO_2.6H_2O$. When exposed to the air, it loses its color and partially disintegrates.

56a. Garnierite.—This variety of genthite is soft and friable. It has a dull luster and a light apple-green to nearly white color. Its composition is very variable but it is essentially a hydrous silicate of magnesium and nickel, whose formula may be $H_2(Ni, Mg)SiO_4 + aq$. It has been identified at the Webster peridotite locality and probably occurs at many of the others. Its softness and dull luster, its unctuous feel, will usually be sufficient to distinguish it from genthite.

Genthite and garnierite are due to the alteration of the peridotites, which usually carry minute quantities of nickel, and this has been deposited as nickel silicates in thin coatings and in seams in the joints and cracks of the rock. They can usually be distinguished from deweylite by their bright green color.

57. *Talc.*

The crystallography of talc is not perfectly understood but it is probably orthorhombic. It is very rarely in crystals, being usually foliated, coarse granular, massive, or sometimes fibrous. The cleavage is basal and perfect. The laminæ are flexible but not elastic and are sectile. Its luster is pearly on the cleavage surface and the color ranges from apple-green to white or silvery white, though it is sometimes darker, from impurities. It is one of the softest minerals, being 1 to 1.5 in hardness and has a very greasy feel. Chemically, talc is a hydrous magnesian silicate, whose formula is $H_2Mg_3Si_4O_{12}$.

The two principal varieties of talc are:

57. Foliated talc.—This consists of folia that are usually easily separated and have a decidedly greasy feel.

57a. Massive steatite or soapstone.—This is coarse granular and of a gray, grayish green to brownish color. The hardness varies from 1 to 2.5. It is sometimes fine granular and soft enough to be used as chalk, as talc pencils.

At many of the peridotite localities, beautiful specimens of foliated talc of an apple-green to greenish white color have been found. These have resulted more often from the alterations of the minerals accompanying the chrysolite in the peridotite rocks than from the alteration of the chrysolite itself. The better specimens have been found at Mine Fork, and near Micaville ford of South Toe River, Yancey County; at the Woody place, Mitchell County; near Webster, Jackson County; and at the Corundum Hill mine, Macon County.

At the Hamlin mine, Ellijay Creek, Macon County, some of the foliated talc has been folded and crumpled, illustrating the strain to which the rocks had been subjected. It is greenish white in color and is represented in B of Plate XXXI. More or less talc-schist is usually developed about the borders of the peridotite and pyroxenite areas throughout the region.

The talc from near Webster, Jackson County, has been analyzed by Dr. Genth[62] as follows:

Analysis of talc from near Webster, Jackson County.

SiO_2	64.44
FeO	1.39
NiO	0.23
MgO	33.19
H_2O	0.34
Al_2O_3	0.48
	100.07

There has also been found near Webster a talc which occurs in minute micaceous scales of a pale yellowish green color, an analysis of which by Mr. Bachman[63] gave:

Analysis of yellowish green, scaly talc from near Webster, Jackson County.

SiO_2	53.91
FeO	1.46
NiO	15.91
MgO	19.39
H_2O	6.30
Al_2O_3	2.65
	99.62
Specific gravity	2.31

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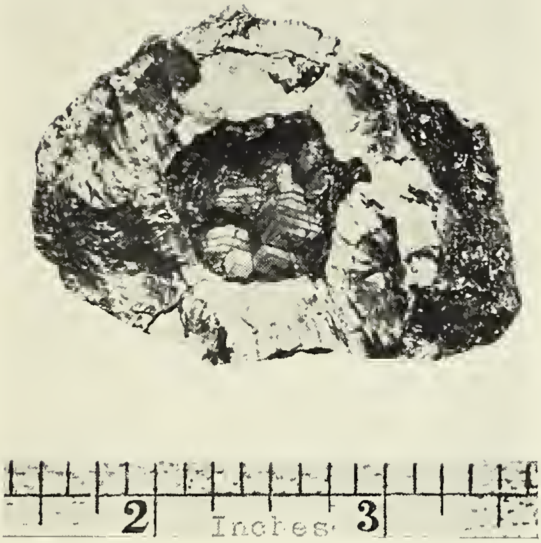
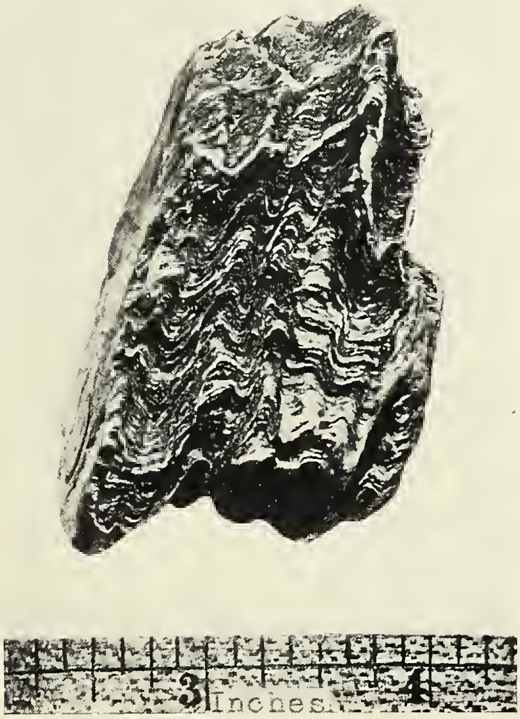
[62] Bull. U. S. Geol. Survey No. 74, p. 61.

[63] Am. Chem. Jour., Vol. VIII, 1886, p. 45.



A, REMNANT OF RHOMBOHEDRAL CORUNDUM IN SHELL OF SECONDARY MASSIVE MARGARITE, HOGSEDS, NEAR ELF, CLAY COUNTY, N. C.



B, CRUMPLED TALC, HAMLIN MINE, MACON COUNTY, N. C.

This would correspond to a talc in which a large proportion of the magnesium has been replaced by nickel.

The soapstone or steatite variety of talc has been found very extensively in the northern portion of the peridotite belt in Watauga, Ashe, and Alleghany counties. Some occurs in Madison and in the southern part of Jackson counties. These have resulted for the most part from the alteration of pyroxenites and pyroxenic peridotites.

58. *Sepiolite or meerschaum.*

This is a compact mineral with a smooth feel and fine, earthy texture. It is 2 to 2.5 in hardness and of grayish white, white and yellowish white colors. It is a hydrous magnesian silicate, whose formula is $H_4Mg_2Si_3O_{10}$.

At Webster, Jackson County, this mineral has been found in thin layers, 1 to 3 mm. thick, in serpentine. This has been analyzed by Mr. P. H. Walker,[64] with the following results:

Analysis of sepiolite from Webster, Jackson County.

SiO_2	55.38
MgO	15.62
NiO	17.84
H_2O	10.77
Fe_2O_3	0.56
	100.17
Specific gravity	2.53

As is seen from the analysis a large per cent of the magnesia has been replaced by nickel oxide.

HYDROUS ALUMINUM SILICATES.

59. *Kaolinite (kaolin).*

Kaolinite crystallizes in the monoclinic system, but it is usually in claylike masses, either compact or friable. Its chemical composition is represented by the formula $H_4Al_2Si_2O_9$.

Ordinarily, kaolin is the result of the alteration of aluminous minerals, principally the feldspars, and where corundum is associated with the feldspar, more or less kaolin has been found. Except as it occurs in this way, no kaolin has been observed associated with corundum. Thus, some kaolin is found with the corundum in gneissoid and granitic rocks. That resulting from the alteration of the feldspars alone is pure white and mixed with more or less free quartz. It is sometimes stained reddish by iron oxide.

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[64] Am. Chem. Jour., Vol. X, 1888, p. 44.

60. Pyrophyllite.

No distinct crystals of this mineral have been observed; it is usually in foliated to fibrous and compact masses. It feels greasy and is from 1 to 2 in hardness. Its color is white, grayish white, and greenish. In many of its physical properties it resembles talc, but chemically it is a hydrous aluminum silicate, whose formula is $H_2Al_2Si_4O_{12}$.

Dr. Genth[65] has described the occurrence of pyrophyllite with corundum at Crowders and Kings mountains in Gaston County.

PHOSPHATES.

61. Apatite.

The crystals of apatite are hexagonal, usually long to short prisms, and are sometimes tabular. They have but an imperfect cleavage and are brittle. While the color is usually sea-green to bluish green, it is often violet blue, and is sometimes white, yellow, red, etc. Apatite is very similar at times to beryl, but it can always be distinguished from this mineral by its hardness, which is but 5, so that it can be scratched with steel. Chemically it is essentially calcium phosphate, with the formula $Ca_4(CaF)(PO_4)_3$.

At a number of the corundum mines, yellowish green to sea-green crystals of apatite have been found. Some of these have the hexagonal prism well developed but none were observed that were terminated. Some measured nearly 1½ inches in length and half an inch to 1 inch in diameter. They have been found most abundantly at the Bad Creek mine, Jackson County, associated with corundum in the biotite. One crystal from the Corundum Hill mine was three fourths of an inch thick and translucent. It has been found only sparingly at the Buck Creek mine, Clay County, where it was enclosed in a mass of zoisite and margarite. At the other two localities mentioned it was encased by biotite-mica.

62. Lazulite.

Lazulite crystallizes in the monoclinic system, the crystals usually being acute pyramidal in habit, sometimes flattened. It also occurs massive and compact, has a hardness of 5 to 6, and is azure-blue in color. Its chemical composition is represented by the formula $RAl_2(OH)_2(PO_4)_2$, where $R = Fe$ and Mg.

It has been found at Crowders and Chubbs mountains in dark blue crystals and crystalline masses with corundum.

An average of two analyses of that from Chubbs mountain[66] gave:

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[65] Am. Phil. Soc., Vol. XIII, 1873, p. 381.

[66] Brush, Am. Jour. Sci., 3d ser., Vol. XVI, 1883, p. 370.

Analysis of lazulite from Chubbs mountain, Gaston County.

P_2O_5	43.76
Al_2O_3	31.70
FeO	8.17
MgO	10.04
H_2O	5.59
SiO_2	1.07
	100.33
Specific gravity	3.122

It is probable that this phosphate is a direct alteration product of corundum and that its mode of formation was similar to that of apatite.

MINERALS ASSOCIATED WITH CORUNDUM NOT FOUND IN NORTH CAROLINA.

A number of other minerals have been found associated with corundum that have not yet been identified in association with corundum in North Carolina. A brief description of them is given here, as some of them may be found later in the corundum fields of this State.

Bauxite.

This mineral, which is a hydroxide of aluminum, is essentially $Al_2O(OH)_4$. It occurs usually in round, concretionary grains, also massive, öolitic, and clay-like. Its color is whitish, grayish to ocher yellow, and brown. In the bauxite deposits of the southern part of France, corundum grains are occasionally enclosed by bauxite.

Gibbsite (Hydrargillite).

Gibbsite crystallizes in the monoclinic system, but often with a hexagonal aspect, and the crystals were originally called hydrargillite. Its color is white, grayish, greenish, and reddish white. It is a hydroxide of aluminum, represented by the formula $Al(OH)_3$.

The usual occurrence of this mineral with corundum is in the form of mamillary or stalactitic incrustations, which sometimes coat the corundum itself and at others the enclosing rock. It has very evidently resulted from the alteration (hydration) of the corundum. It was first noticed at Gummuch Dagh, Asia Minor, and later at Unionville, Pa.

Calcite.

Calcite has been observed as an associated mineral of corundum only where the latter occurs in limestone, as in New Jersey and in the Burmah ruby district of India.

Calcite crystallizes in the rhombohedral division of the hexagonal system and has a perfect rhombohedral cleavage. It is 3 in hardness. In color it is usually white to colorless, sometimes pink and blue. Its chemical composition is a calcium carbonate, $CaCO_3$ (see magnesite, p. 282).

Orthoclase.

This feldspar (see p. 222) is an associate of the corundum that occurs in syenite, as that from Montana and Canada.

Barsowite.[67]

This variety of anorthite feldspar (see p. 228) occurs with corundum at Barsowskoi, near Kyschtimsk, in the Ural Mountains.

Nephelite (Nepheline).

At the recently discovered corundum localities in Ontario, Canada, nephelite occurs very abundantly as a constituent of the nepheline-syenite, the matrix of the corundum. As the percentage of corundum in the rock increases, that of the nephelite decreases.

This mineral crystallizes in the hexagonal system and occurs in massive, compact form, and in imbedded grains. It is colorless, white, yellowish, and when massive, is sometimes dark green, greenish or bluish gray. Its formula is $R_8Al_8Si_9O_{34}$ where $R = Na$ and K.

Sodalite.

This mineral crystallizes in the isometric system, the dodecahedron being the common form, but is usually found massive or in embedded grains. It varies in color from gray to blue. It has been found as an associate of corundum in the nepheline-syenites of Canada.

Paragonite.

This mineral belongs to the muscovite group and represents the soda-mica, corresponding to muscovite in composition $(HNa)AlSiO_4$ (see p. 312 for description of this group). Corundum occurs in a paragonite schist near Schwarzenberg, in Saxony.

Euphyllite.—This is a variety of paragonite that is between this and muscovite and is found associated with corundum at Unionville, Pa. A beautiful emerald-green mica associated with corundum at Pipra, South Rewah, India, is also referred to this mineral.

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[67] Rose, Pogg. Ann., Vol. XLVIII, 1839, p. 567.

Pattersonite.

Pattersonite is a micaceous mineral, of the chlorite group, that occurs with corundum at Unionvile, Pa. For a description of the chlorites see p. 317.

Painterite.

This is a vermiculite of a dull green color, described by Clarke from Newlin township, Chester County, Pennsylvania. The group of vermiculites is described on p. 319.

Lesleyite (Ephesite).

These are names that were given to an alteration product of corundum that was later proved to be a mixture of the potash mica, muscovite (damourite), and corundum.

Zircon.

This mineral has been found as an associate of corundum in the gneissic rocks of the Haute-Loire, France. It has also been found in the same belt of syenite rocks of Ontario, Canada, in which the corundum has been found, but not as yet directly with the corundum.

It crystallizes in the tetragonal system and is more commonly in square, prismatic crystals. The color varies usually from grayish, brownish yellow to reddish brown; also colorless, yellowish green, and orange. It is a zirconium silicate whose formula is $ZrSiO_4$.

MINERALS ASSOCIATED WITH RUBIES FROM COWEE VALLEY.

A list of the minerals found with the rubies in the gravels of Caler Fork of Cowee Creek is given here for the reason that many of them may be found to be true associated minerals of corundum when the origin of the rubies has been determined. The possibility that these originated from a hornblende-eclogite makes it very probable that many of the minerals in this list will be found to be component parts of the same rock. Some of the minerals are especially characteristic ones, such as are formed by contact metamorphism.

The minerals found are: gold, pyrite, chalcopyrite, nickeliferous pyrrhotite, sphalerite (blende), sperrylite (the rare platinum arsenide), ilmenite or menaccanite, rutile, bronzite (in clear transparent masses or fragments), hornblende (a rich soda variety), zircon (in very brilliant colorless and reddish crystals, 0.5 to 2 mm. in length and perfect in their development), sillimanite, cyanite, staurolite (in clear transparent fragments), iolite (colorless), and monazite.

CHAPTER X.

ORIGIN OF CORUNDUM.

ARTIFICIAL PRODUCTION OF CORUNDUM.

Corundum has been produced synthetically by several methods and the results are very satisfactory, the mineral having been obtained in many forms and colors. The artificial production of the corundum gems was the first problem that attracted the attention of workers in this line, and splendid results have been obtained in the manufacture of sapphires and rubies.[1]

In 1837 and later in 1857, Gaudin[2] found that upon heating a closed crucible containing equal parts of alum, sulphate of potash, and charcoal before the oxyhydrogen blowpipe, corundum was one of the products of the reaction.

In 1851 De Sénarmont[3] obtained rhombohedrons of corundum by heating a solution of aluminum chloride or nitrate in a sealed tube to a temperature of 350° C. During the same year Ebelmann[4] produced hexagonal plates of corundum by exposing to a very high temperature in a porcelain kiln a platinum crucible containing one part of amorphous alumina and three or four parts of borax. Carbonate of soda may replace the borax in this production of corundum. By the addition of small quantities of different metallic oxides, various colors of corundum were obtained.

Elsner[5] obtained red crystalline grains of corundum by fusing, before the oxyhydrogen blowpipe, anhydrous alumina with bichromite of potash.

Saint-Claire Deville and Caron[6] in 1858 produced magnificent hexagonal plates of corundum by heating at a white heat for an hour anhydrous aluminum fluoride in the bottom of a charcoal crucible, suspended in the center of which was a cupel of the same material filled with boracic acid. By adding a little chromium fluoride in varying amounts, red, blue, or green corundum was obtained.

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[1] Encyclopedie Chimique, Tome II. Reproduction Artificielle des Mineraux, par M. L. Bourgeois; and Trans. N. Y. Acad. Sci., Oct. 4, 1886, On the New Artificial Rubies, by G. F. Kunz.

[2] Comptes Rendus, Vol. IV, 1837, p. 999; Vol. XLIV, p. 716; L. Inst., Vol. XXV, p. 110; J. Prakt. Chem., Vol. LXX, p. 381; Bull. Univ. de Generi, XXXIV, p. 68; and Jahr. f. Min., 1857, p. 444. Forqué and Lévy, Synth. Min. et Roches, p. 218.

[3] Comptes Rendus, Vol. XXXII, 1851, p. 762; L. Inst., 1851, p. 165; Ann. Chem. Phar., Vol. LXXX, p. 214; and Phar. Centl., 1851, p. 518.

[4] Ann. de Phys. et de Chimie, 1851, Vol. XXXIII, p. 34.

[5] Jour. Prakt. Chem., Vol. XVII, p. 175.

[6] Comptes Rendus, 1858, Vol. XLVI, p. 764; L. Inst., 1858, p. 133; Ann. Chem. Phar., Vol. CVIII, p. 55; Duglpal. Jour., Vol. CXLVIII, p. 372; and J. Prakt. Chem., Vol. LXXIV, p. 157.

In the year 1861 Debray,[7] found that corundum was formed by passing a slow current of hydrochloric acid over aluminate of soda at a red heat, or over a mixture of aluminum phosphate and lime. He also produced crystals of corundum by melting phosphate of alumina with 3 or 4 times its weight of potassium or sodium sulphate.

M. Hautefeuille[8] in 1865 produced corundum crystals by passing hydrofluoric acid gas slowly over amorphous alumina heated to a bright red heat in a platinum tube, the gas having been previously diluted with nitrogen and steam.

Gaudin,[9] in 1869, obtained corundum by the decomposition of potash alum by charcoal; and also by fusing amorphous alumina in the oxyhydrogen blowpipe flame. The fusion when cooled has the hardness of corundum, but a specific gravity of only 3.45.

Frémy and Feil[10] produced corundum in 1877 by the action of minium ($2PBO.PbO_2$) and alumina in siliceous earthen crucibles, by the fusion of which a lead aluminate was formed and this, uniting with the silica of the crucible to form a lead glass, liberated the alumina, which crystallized out as corundum in hexagonal plates. The specific gravity of these crystals was 4.0-4.1. By the addition of a chromium salt, a ruby corundum was produced which had the color and hardness of the natural ruby and which, like this, was decolorized temporarily by heating. They also obtained corundum, in the form of sharply crystallized rubies, by fusing together equal weights of alumina and barium fluoride with a little potassium bichromate in a clay crucible covered with another inverted.

In 1880, St. Meumer,[11] by heating aluminum chloride and water vapor with either magnesium or zinc to redness in a porcelain tube, obtained minute crystals which were thought to be corundum but which were too small for exact determination.

In 1882, H. Grandeau[12] obtained corundum in the same manner as

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[7] Comptes Rendus, Vol. LII, 1861, p. 985; L. Inst., 1861, p. 165; Ann. Chem. Phar., Vol. CXX, p. 184; Jahrb. für Min., 1861, p. 702; Bull. Soc. Chem., 1865.

[8] Ann. Chim. Phys., Vol. IV, 1865, p. 153.

[9] Comptes Rendus, Vol. LXIX, 1869, p. 1342; and Dana Min., 1892, p. 213.

[10] Comptes Rendus, Vol. LXXXV, 1877, p. 1029; and Dana Min., 1892, p. 213.

[11] Comptes Rendus, Vol. XC, 1880, p. 701.

[12] Comptes Rendus, Vol. XCV, 1882, p. 921.

Debray, and he calls attention to the formation of a double phosphate of alumina and potash with the corundum.

By treating freshly precipitated alumina $Al(OH)_3$, at a temperature of 300°, with water containing a trace of ammonium fluoride, Bruhms[13] in 1889 obtained small hexagonal crystals of corundum with pyramidal terminations. Freshly precipitated ferric hydroxide treated at 250° in the same manner gave small hexagonal plates of hematite.

Lacroix[14] has shown that by the destruction of acid inclusions in certain basic magmas (as basalts, trachytes, and andesites), corundum, zircon, diaspore. etc., were produced, and states that this may be the origin of the corundum and zircon in Haute-Loire.

Friedel[15] in 1891 described experiments in which amorphous alumina was heated in a solution of soda at a temperature of 530° in a closed tube. In this reaction, the excess of alumina separated out as corundum. When the temperature was raised to but 400°, only diaspore was produced; at 450°-500°, both corundum and diaspore were obtained; while from 530°-535°, only corundum. When the soda contains a small amount of aluminum and calcium carbonates, small crystals of calcite are obtained with the corundum.

By the action of alumina, with more or less potash, and barium fluoride heated to very high temperature in an earthen crucible, Frémy[16] obtained in 1891, ruby corundum that was well crystallized, clear, and of a brilliant color, potassium bicarbonate having been used as a coloring matter. Corundum[17] has also been produced by the action of aluminum chloride on lime.

One of the most instructive artificial productions of corundum is that from molten magmas whose chemical composition is approximately that of known rocks. This synthetic production of corundum has aided very materially in solving the problems regarding the origin of corundum in nature.

Hautefeuille[18] has described the production of corundum by dissolving alumina in nepheline, which gave a vitreous paste from which many hexagonal plates of corundum were produced.

Morozewicz[19] in his recent elaborate work on the "Experimental Investigation of the Formation of the Minerals in an Igneous Magma" describes the formation of corundum from many of the magmas that were supersaturated with alumina. The supersaturated alumina silicate magmas had the general composition $MeO.mAl_2O_3.nSiO_2$ ($Me = K_2$, Na_2, Ca; $n = 2\text{-}13$). These magmas in cooling throw out all their excess of alumina (over $m = 1$) in the form of corundum crystals, this taking place when magnesia and iron are not present (see also page 354).

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[13] Bruhms Neues Jahrb. für. Min., Vol. II, 1889, p. 62; and Am. Nat., July, 1890, p. 671.

[14] Bull. Soc. France de Min., Vol. XIII, 1890, p. 100.

[15] Bull. Soc. France de Min., Vol. XIV, 1891, p. 7.

[16] Synthesis des Rubies (Paris), 1891.

[17] Dana Min., 1892, p. 213.

[18] Bull. Soc. France de Min., Vol. XIII, 1890, p. 147; and Am. Nat., Nov., 1890, p. 1076.

[19] Tschermak, Min. u. Petrog. Mitt., Vol. XVIII, 1898, pp. 1-90 and 105-240.

In the crystallization of an anorthite-nepheline magma which did not contain any magnesia, the principal products were corundum, anorthite and nepheline.

In these experiments the metallic silicates that were used to form the magma were for the most part silicates of calcium, sodium, and potassium. When alumina was present in these magmas in excess of $m = 1$, it would separate out in the form of corundum, but when the magma was not saturated with Al_2O_3, or m was equal to 1 or less, all the alumina was used up in forming the double silicates. When magnesia was present in magmas of this type, the excess of alumina united with the magnesia to form the mineral spinel, and if not enough magnesia were present to unite with all of the alumina, some corundum would be formed. When, however, there was an excess of silica or n is greater than 6, the excess of alumina united with the silica to form the mineral sillimanite and the over excess of alumina separated out as corundum. But when magnesia and iron were present with the excess of silica and alumina, cordierite and spinel were the minerals formed.

In the reduction of certain of the rarer metallic oxides by the aid of powdered metallic aluminum, corundum is one of the products of the reaction, which is dependent upon the strong affinity of the aluminum for oxygen. In this reaction the metallic oxides are mixed in a refractory crucible with finely powdered aluminum and barium peroxide, the latter containing an excess of oxygen and being readily ignited. Barium peroxide is also added to the top of the mixed oxides and aluminum, and then a little more of the powdered aluminum is placed on top of the barium peroxide. The barium peroxide is readily ignited by a wax taper or other fuse, and the heat generated, together with the excess of oxygen, is sufficient to ignite the powdered aluminum. This at once oxidizes and the reaction continues throughout the mixture in the crucible, the aluminum readily taking up the oxygen from the metallic oxides present and reducing them to pure metallic state. The heat generated by the reaction leaves the mass in a molten condition, the metals settling to the bottom and the alumina separating out as corundum. Metals such as chromium, titanium, tungsten, vanadium, molybdenum, etc., that were formerly considered almost impossible to reduce to the metallic state, can now be obtained with comparative ease and at small expense. The corundum obtained varies in color, and is dependent to a certain extent upon the metallic oxide reduced.

In 1900 a process was devised for manufacturing corundum out of bauxite. This method is in part a secret process, but consists essentially of subjecting the bauxite to a very great heat in an electrical furnace.

The idea that bauxite is changed into corundum by heat and pressure is not new, for in 1861 Dr. T. Sterry Hunt, of the Geological Survey of Canada, in an article on "The origin of some magnesian and aluminous rocks," described the occurrence of bauxite at Baux, in the south of France, and stated that "by an intense heat this substance is converted into crystalline corundum resembling emery in its physical character."

The Norton Emery Wheel Company has erected a plant at Niagara Falls for the manufacture of artificial corundum and the manufactured corundum, which is known commercially as alundum, gives very good results as an abrasive. In the manufacture of this artificial corundum, a specially constructed furnace is used in which, the bauxite itself is utilized as a lining. The heat generated is sufficient to fuse the bauxite which recrystallizes as corundum. The pig, as it is taken from the furnace, has an outer layer of nearly unaltered bauxite. A portion of the corundum is well crystallized in hexagonal plates.

NATURAL PRODUCTION OF CORUNDUM.

Corundum is formed in nature by several different methods, as would be inferred from the many different ways in which the mineral occurs. Corundum that is associated with the metamorphic gneisses and schists, must be of different origin from that found in the basic igneous rocks; and that occurring in syenite must have originated in a different manner from that found in crystalline limestone. Alumina is now known to be soluble in many molten magmas, and as these cool, corundum separates out. The hydrous oxide of alumina can be converted by means of heat and pressure into corundum, and the occurrence of this mineral in metamorphic rocks may in some cases be due to the change of the hydrous oxide, which was perhaps in the form of bauxite.

The methods of formation of the corundum associated with the different rocks in North Carolina are discussed in the following pages.

ORIGIN OF CORUNDUM IN PERIDOTITES.

REVIEW OF LITERATURE.

In 1872, Dr. C. U. Sheppard,[20] in an extended article on the corundum of North Carolina and Georgia, describes the occurrences of corundum and chrysolite, the associated minerals and what he calls the development of the "strata" which exhibit the following order of formations: "(1) Chrysolitic rock somewhat mixed with anthophyllite; (2) a layer of micaceous rock; (3) a seam of chalcedony; (4) a stratum of chloritic rock (ripidolite); (5) the same through which the corundum is regularly diffused sometimes in narrow veins or widening out to several feet." Nowhere in this article does he suggest the probable origin of the corundum.

Dr. J. Lawrence Smith,[21] in describing the occurrence of corundum associated with the peridotites of North Carolina and Georgia, states that all the localities of corundum that he has observed or examined exhibit certain prominent characteristics common to all, but that each locality has its own peculiar characteristics. He says that in all cases, however, the masses of corundum give evidence of having been formed by a process of segregation, which he has described in a memoir,[22] on the Asia Minor emery; that by the exercise of homogeneous and chemical attractions, the minerals which constitute and are associated with emery were separated out from the calcareous rock before it consolidated.

Dr. F. A. Genth,[23] although not touching directly on the origin of corundum or giving any evidence to sustain his statement, says, "that at the great period when the chromiferous-chrysolite beds were deposited a large quantity of alumina was separated, which formed beds of corundum." This corundum has subsequently been acted upon and altered and changed into various minerals; that the "veins" of chlorite, etc., are alterations of the original mass of corundum and that the corundum might be found in a less altered or wholly unaltered condition when the vein was explored below the action of surface influences. In speaking of the corundum crystals imbedded in the chlorite, Dr. Genth says the crystals "appear to have formed after a great portion of the original corundum had changed into chlorite, as if there had been an excess of alumina ready for combination, which, not finding a supply of the requisite amount of silicic acid and bases, had again crystallized as corundum."

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[20] Am. Jour. Sci., Vols. III, IV, 1872, pp. 109-114, 175-177.

[21] Am. Jour. Sci., Vols. III, VI, 1873, pp. 180-6.

[22] Am. Jour. Sci., 2d ser., Vol. X, 1850, p. 354.

[23] Proc. Am. Phil. Soc., Vol. XIII, 1873, pp. 361-406; and Am. Journ. Sci., 3d ser., Vol. VI, 1873, pp. 461-462 (review).

In an article on corundum and its associated rocks, Dr. C. D. Smith[24] points out the facts that led to his belief in the igneous origin of the peridotites, but does not discuss them. He calls attention to the occurrence of corundum chiefly in chlorite veins and says "the chlorite seems to have been first crystallized, and then, the alumina of which the corundum is composed was evidently in a state of solution and must have permeated the chlorite either in thermal waters or steam." The only points given to sustain this theory are that plates or scales of chlorite are sometimes enclosed in the corundum and that corundum has been observed that conforms in its faces and general shapes to the chlorite that is present. The other points bearing on the origin of the corundum that he undoubtedly had in mind he makes no mention of in his article. Dr. Smith also states that he found "chrysolite attached as an enveloping matter to considerable masses of corundum." He makes, however, apparently no further mention of this occurrence in any of his writings.

In a description of the "Jenks corundum mine," Dr. R. W. Raymond[25] calls attention to the occurrence of transparent nodules of corundum in a matrix of the same mineral, and also of the great variation in the appearance of the corundum from the different veins. One of the veins has produced more of the gem material, while it contains but few large masses of the corundum.

Dr. A. A. Julien,[26] in his paper, on "The Dunyte-beds of N. C.," considers the corundum in all cases a secondary or alteration product, and explains all the phenomena of alteration in the veins by the introduction of a solution of soda and alumina into the fissures, during the period of alteration and metamorphism, believing at the time that the dunite was of sedimentary origin.

In an article commenting on Julien's theory regarding the origin of the peridotites, Dr. M. E. Wadsworth[27] in speaking of the corundum, says that the corundum is looked upon as a secondary mineral, and not as Genth held, the primary material from which many minerals originated.

Dr. T. M. Chatard,[28] made a very careful chemical study of the material collected across the contact between the gneiss and dunite at Corundum Hill. He points out as a result of his chemical analyses, that starting from the gneiss there is a progressive increase of magnesia in the vein material as the dunite is approached, and that there is a proportionate decrease in the percentage of alumina.

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[24] Report of North Carolina Geol. Surv., Vol. I, 1875, p. 91.

[25] Trans. Am. Inst. of Min. Engrs., Vol. VII, 1879, p. 89.

[26] Nat. Hist. Soc., Boston, Vol. XXII, 1882, pp. 141-149.

[27] Science, Vol. III, 1884, p. 486.

[28] Bull. U. S. Geol. Survey No. 42, pp. 45-63.

From these analyses, the series from the section across the vein are divided into three groups, aluminum silicates, aluminum-magnesium silicates, and magnesium silicates. The middle term of this chemical series is also the middle number of the field series. He regards the corundum as an accessory mineral, for frequently it is not found at all in the vein, and sometimes in but small amount, and therefore to be considered as the result of a certain balance between the magnesium and aluminum silicates, which have by their union produced the chlorite and vermiculites.

In describing the occurrence of corundum at Chester County, Pa., Prof. J. P. Lesley,[29] holding the view that the serpentines are of sedimentary origin, considers the corundum as derived from a clay consisting largely of alumina and says that "it seems difficult to imagine its excessive compact hardness as produced in any other way than by heat."

Prof. J. V. Lewis'[30] report on "Corundum and the Basic Magnesium Rock in North Carolina" is mainly a report of field observations and does not take up any discussion of facts bearing on the origin of the corundum, though many points of interest and importance are brought out regarding the alterations of the dunite and of the character of the vein and vein materials and also concerning the alteration of corundum.

The corundum deposits of Georgia are similar to, almost identical with, those in North Carolina. Mr. F. P. King,[31] in his report on the corundum deposits of Georgia, which is principally devoted to the description of localities, occurrences, and varieties of corundum, etc., comes to the conclusion that corundum is an accessory mineral and that its presence is occasioned by an excess of alumina in the rock masses "chrysolite, gneiss, and hornblende gneiss." This is explained by the alteration of these rocks into magnesium silicates, alkaline salts, and ferro-silicates, which, in conjunction with carbonic acid of percolating waters would dissolve the combined alumina, and produce, on crystallization, all the minerals associated with corundum; and when the alumina is in excess this would produce corundum itself.

As has been shown above, a number of hypotheses concerning the origin of the corundum have been advanced. With one exception, however, they are all prior to the numerous and elaborate experiments that have been made by different investigators on the solubility of alumina in a molten basic glass and the separating out of corundum and spinel crystals from this on cooling. They are also prior to Vogt's[32] very important investigations into the igneous origin of certain ore deposits. All these experiments have aided very materially in solving the numerous problems in relation to the origin of many of the ores; and in the present investigation the facts proved by these experiments have been of exceptional assistance in the compiling of evidence to substantiate the theory proposed.

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[29] Pennsylvania Geol. Survey, C 4, 1883, p. 352.

[30] Bull. North Carolina Survey No. 11.

[31] Bull. Georgia Geol. Survey No. 2.

RELATIONS OF CORUNDUM TO THE PERIDOTITES.

In all the field observations a careful search was made to find the corundum directly in contact with the peridotite, and this was observed at one locality. At the Hayes (Egypt) mine, on the western slopes of the Sampson Mountains, about 10 miles west of Burnsville, in Yancey County, several specimens have been found showing corundum crystals entirely surrounded by granular peridotite (dunite), and none of the chlorite minerals usually present with the corundum (fig. 21). Both the dunite and the corundum have altered somewhat, the corundum having a little muscovite developed on its basal termination, while the dunite is stained a yellowish brown and is rather friable. The specimens that were examined were collected by Mr. U. S. Hayes, who was prospecting in the vicinity of the mine. No mining was being done when this locality was visited, but miners living in the vicinity, and who have worked in the mine, report the finding of many fragments of corundum in the dunite similar to the one here figured, and several were in the possession of Mr. Hayes at the time.

Although this is the only locality where corundum was found directly surrounded by peridotite, it has been reported to have been found, both by Dr. J. Lawrence Smith and Dr. C. D. Smith. It has been observed in serpentine, which is the commonest alteration product of the dunite variety of peridotite. At the Buck Creek mine, Clay County, corundum was found that was bordered with serpentine. Some of the specimens observed show small particles of corundum either entirely or partially surrounded by serpentine and the whole mass of corundum and serpentine surrounded by clinochlore. In another specimen a streak of corundum about an inch thick lies between two zones of serpentine, from a quarter to three quarters of an inch thick, and these in turn are bordered by a talcose and enstatite rock (fig. 22).

The best crystals of corundum have been found at Corundum Hill, where the crystals project from bodies of massive corundum, and are often partly or entirely inclosed in chlorite. In other cases separate corundum crystals are imbedded in chlorite. Many of the crystals, especially those free from alteration and decomposition or those only slightly altered, are usually well developed, with smooth, even faces and sharp edges.

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[32] Zeitschr. für Prakt. Geol. Nos. 1, 4, and 7, 1893.

In a number of the mines, corundum is found in contact with and surrounded by spinel. At the Carter mine, near Democrat, Buncombe County, corundum is found in white and pink masses, intergrown with a greenish black massive spinel. In thin splinters the spinel is of a very handsome emerald-green color. The masses of corundum and spinel are partially surrounded by a deep-green chlorite, which has also been developed in places in small greenish scales between the corundum and spinel, though the contact of the spinel and of the corundum is usually sharp and distinct, showing no sign of alteration. Minute scales of greenish chlorite occur rarely in the corundum and spinel near the junction of these minerals with the external mass of the chlorite. All the massive corundum shows the characteristic parting lines, and the spinel shows distinctly a conchoidal fracture.

A massive, coarsely to finely granular spinel is found at the Corundum Hill mine, Macon County, which has disseminated through it small grains and fragments of pink and white corundum. The spinel and corundum are closely associated with chlorite, which is here more generally developed between the corundum and spinel and in the spinel (between the granules) than it was at the Carter mine. The spinel in the mass appears black, but in small splinters it shows a green color.

The corundum is found in the peridotite in two different relations, (1) in the zone of alteration products developed at the contact of the peridotite and the gneiss, "peripheral or border veins," and (2) in a similar zone of alteration products that is bounded on both sides by peridotite, "interior veins."

The line of contact between the zone of alteration products and the gneiss is very sharp and distinct in all the border veins examined. The minerals developed between the corundum-bearing zone and the dunite are very abundant and are different from those between this zone and the gneiss. In the veins that are entirely within the peridotite the zones of alteration products contain the same minerals on each side of the corundum, and these minerals are similar to those on the peridotite side of a border vein. These phenomena are described and illustrated on page 201.

The appearance and character of the veins vary according as they are border veins or interior veins. In an interior vein the approximate trend of the vein is toward the center of the mass of peridotite. As these veins penetrate the peridotite mass they usually grow thinner and thinner until they pinch out. This is especially a prominent feature at Buck Creek, Clay County, N. C., and at Laurel Creek, Rabun County, Ga.

In a border vein, however, the corundum seems to extend downward indefinitely along the contact. Supplementary veins are often encountered branching off from a border vein, toward the center of the peridotite, and these, like other interior veins, gradually diminish until they pinch out entirely. This variation in the occurrence of the corundum in the different veins has been observed by many of those who have prospected for and mined corundum in this region.

THEORY OF ORIGIN.

The foregoing summary of facts, and the observations and conclusions of the preceding chapters of this report, when viewed in the light of the studies of Vogt, Morozewicz, and Lagorio referred to below, lead naturally to the conclusion that the corundum was held in solution in the molten magma of the peridotite when it was intruded into the country rock and that it separated out among the first minerals segregated as the mass began to cool. The peridotite magma containing the chemical elements of the different minerals would act like a saturated solution and as it began to cool the minerals would crystallize out, in the reverse order of their solubility in the molten magma; that is, not the least fusible but the least soluble mineral would crystallize first and so on. The more basic portions, according to the general law of cooling and crystallizing magmas, being the most insoluble, would therefore be the first to separate out. They would be the oxides containing no silica, which in the present case would be the alumina and chrome spinels and the corundum.

Morozewicz[33] has shown by some very important experiments that molten glass of a character similar to the basic magnesian rocks dissolves alumina readily, and as this molten mass began to cool, corundum and spinel were the first minerals to separate out. According to this, the corundum and spinel would be the first to crystallize or solidify out from the molten mass of the peridotite as this began to cool, and this solidification would take place first on the outer border of the mass, because here it would cool first. Convection currents would then tend to bring a new supply of material carrying alumina into this outer zone, and when this was reached, crystallization would take place and the alumina would be deposited as corundum.

This is essentially the idea advanced by Becker[34] in a paper on "Fractional crystallization of rocks," and where this process has taken place in dikes and laccolites, a concentration is observed of the earlier and more basic minerals at their outer boundary.

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[33] Zeitschr. für Kryst., Vol. XXIV, 1895, p. 281.

[34] Am. Jour. Sci., 4th ser., Vol. IX, 1897, p. 259.

The more basic the magma the more fluid it is likely to be and the greater the tendency for this process to take place, as is shown by many well-known instances of the separation of ilmenite, pyrrhotite, etc., from gabbro magmas, as described by Vogt, Adams and others.

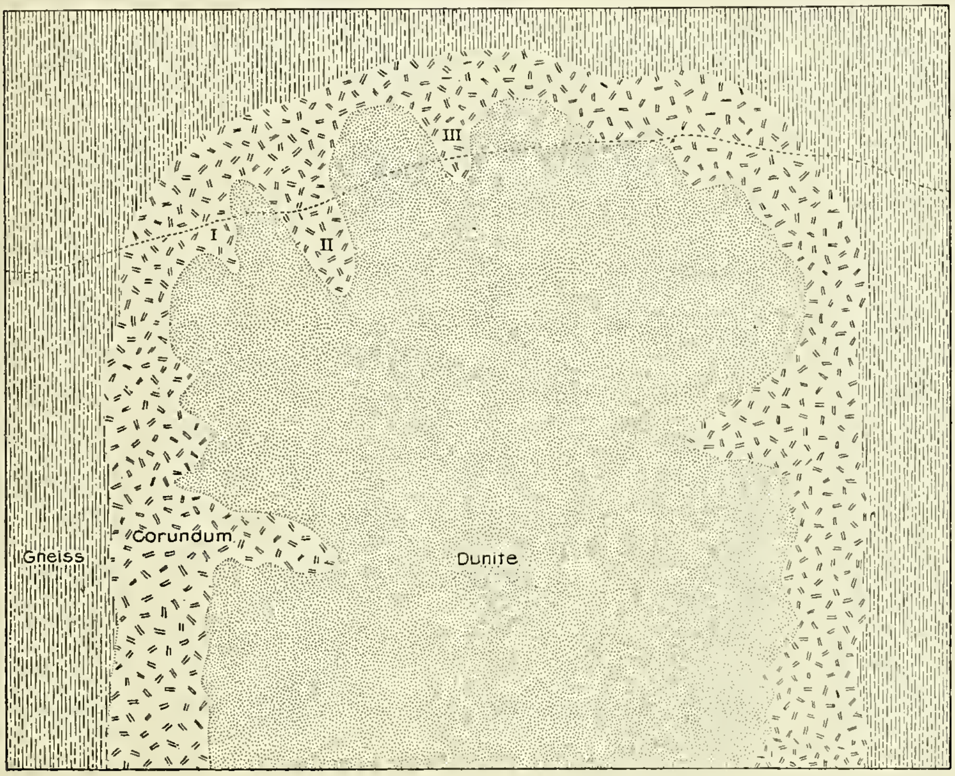

FIG. 33.—Ideal vertical cross-section of a mass of peridotite soon after its intrusion into gneiss.

Figure 33 is a diagrammatic vertical cross-section of a mass of peridotite as it would appear soon after its intrusion into a gneiss, when it held in solution a large amount of alumina which separated out as corundum. In this figure the proportion of corundum zone has been greatly exaggerated for the sake of distinctness. The corundum would be concentrated toward the borders of the peridotite and would make a sharp and nearly regular contact with the gneiss. Its contact with the peridotite, however, would at some places be sharp and regular, while at others it would be very irregular, showing masses of corundum penetrating the peridotite.

The extensive erosion to which the rocks in this mountain region have been subjected has worn them down to their present condition, represented by the dotted lines in fig. 33.

The interior veins, I, II and III in fig. 33, which at the present time have no connection with one another but are each separate and distinct, were at the time of their formation part of the corundum concentrated along the border of the peridotite. Some of these veins would soon be worked out, while others might extend for a hundred feet or more without any apparent change in size (Pl. XX, A and B).

This explanation will account for all the variations observed in the occurrence of the corundum in the different veins.

The corundum crystallizing out from the molten peridotite, which would be a very basic magma, would be concentrated toward the margins, where at many places, there would be a sharp separation between the corundum and the peridotite; while at others there would be more or less corundum in the form of masses and particles that would extend beyond the main mass and into the peridotite and would present the appearance of a somewhat gradual passage from corundum to pure peridotite, as illustrated in fig. 34.

The varying pressure, temperature, and other physical conditions during and after intrusion would affect the crystallization of the minerals from the molten mass, and thus would arise the great variation observed in the corundum found in the same mass of peridotite. Thus, at Corundum Hill there occur masses of block corundum, large rough crystals, small well developed crystals, and particles or grains of corundum.

The differentiation of the basic peridotite magma upon cooling is similar to that described by Vogt[35] and Adams[36] in connection with the separation of sulphide deposits from a molten gabbro magma. These ores are usually segregated or concentrated near the contact of the gabbro with the gneiss and are always sharply separated from the gneiss. While there is at some places a distinct line of separation between the ore and the gabbro, at others there is a gradual transition from the ore to the pure gabbro. It might be expected that the corundum would be surrounded in a similar manner by peridotite; yet, as was stated above, there is but one locality known where corundum is so enclosed. The absence of any general occurrence of corundum is readily explained by the ease with which the peridotite itself suffers decomposition.

The corundum concentrated in the peridotite near its contact with the gneiss where the thermal waters coming in contact with the heated masses acted most powerfully, furnished alumina for reacting with the peridotite to form the aluminum-magnesium silicates surrounding the corundum. That the peridotite decomposes very readily is apparent from numerous specimens of the dunite that are completely surrounded by secondary minerals that must have been formed at its expense. Corundum has been found in serpentine but this is often surrounded by chlorite.

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[35] Zeitschr. für Prak. Geol., Nos. 1, 4, and 7. 1893.

[36] On the Igneous Origin of Certain Ore Deposits: read before the Gen. Ass. of Prov. of Quebec, Montreal, Jan. 12, 1894.

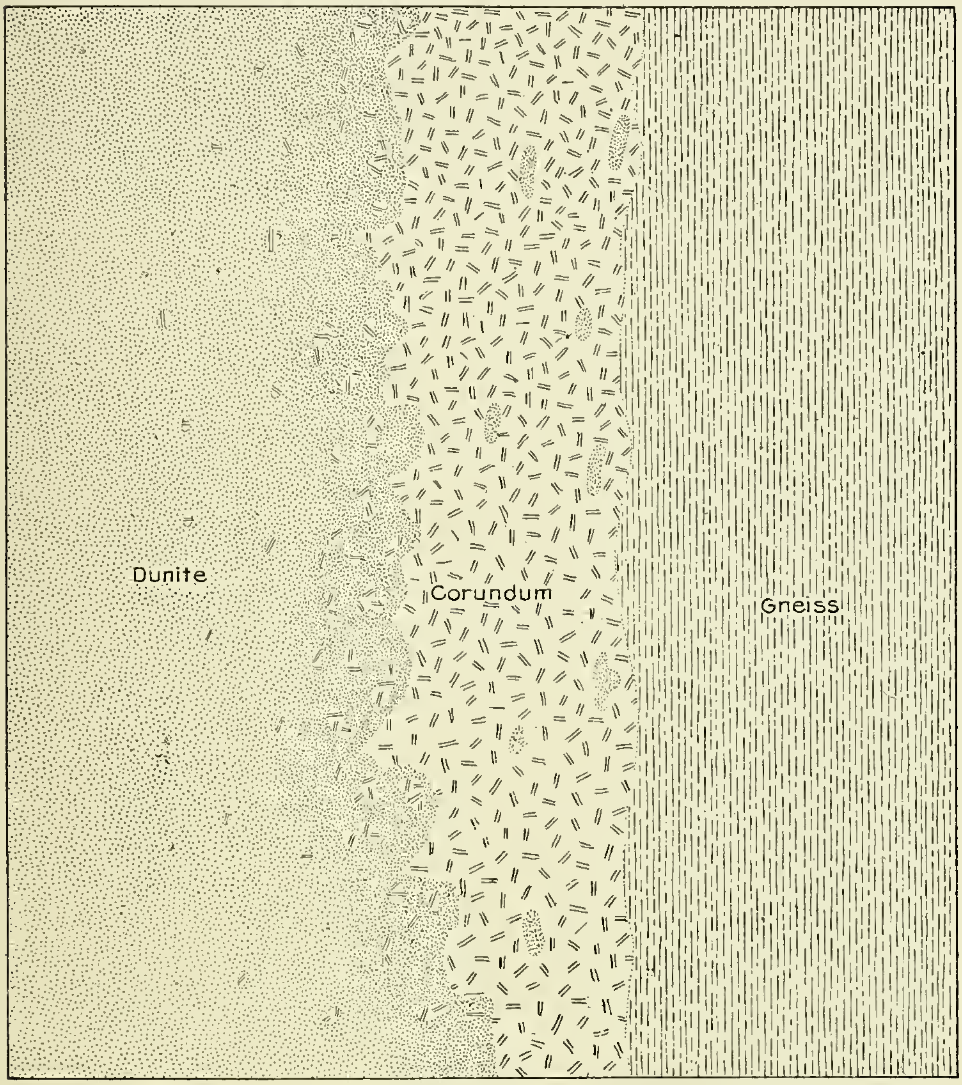

FIG. 34.—Ideal vertical cross-section, showing a somewhat gradual transition from corundum to peridotite.

The descriptions of the cross-sections of corundum veins given on pages 201, 202, are similar to those described by Shepard,[37] Chatard,[38] and Lewis,[39] and show practically the same sequence.

As the peridotite and corundum began to alter and decompose under the influence of the deeper waters, for a time more or less heated, many decomposition minerals would be formed on the peridotite side of the vein and a few on the gneiss side. The secondary products next the gneisses would vary in character according to the amount of the peridotite that had been held between the corundum and the gneiss (fig. 34). The common decomposition product surrounding the corundum is chlorite (clinochlore) or an altered form of this mineral belonging to the vermicultes.

Between the corundum imbedded in the chlorite and the gneiss there is often but very little and at times no chlorite or vermiculites developed, the corundum-bearing portion of the zone being apparently in direct contact with the gneiss (*b* of cross-section, p. 202).

In the interior veins the alteration products developed are the same on both sides of the corundum-bearing zone and are in most cases nearly an exact reproduction of the peridotite side of a border-vein (figs. 19 and 20). This shows that the gneiss had no influence in the formation of the alteration products of the border-veins.

Dr. Chatard's analyses show that there is an increase in magnesia and decrease in alumina as the peridotite is approached, and this is in harmony with the present theory regarding the formation of the alteration products.

The penetration of the gneiss by molten material carrying corundum during the differentiation of the molten peridotite would explain the occurrence of corundum that is sometimes found in the gneiss next to a border-vein. A similar occurrence of sulphides that penetrated gneiss during the cooling and differentiation of a molten gabbro, is noted by Vogt[40] and has been referred to by Adams.[41]

Pirsson's[42] theory regarding the origin of the Montana sapphires, which occur in a basic igneous dike,[43] is that these crystals separated out from the molten magma as this began to cool. He points out that originally the rock could not have been sufficiently rich in alumina to have allowed a general separation out of that material, and undoubtedly the magma took up quantities of inclusions from the sediments through which it passed. Clay shales, or rocks of similar composition, must have been among these sediments; and fragments of this shale would be dissolved by the basic magma from which, on cooling, the alumina would separate out as corundum. In this connection, attention may be called to the origin of the corundum found in the quartz-schists of Clay County, described on page 356.

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[37] Am. Jour. Sci., 3d ser., Vol. IV, 1872, p. 111.

[38] Bull. U. S. Geol. Survey No. 42, 1887, p. 49.

[39] Bull. North Carolina Survey No. 11, 1896, p. 93.

[40] Bull. U. S. Geol. Survey No. 42, pp. 50-56.

[41] Already cited.

[42] Am. Jour. Sci., 4th ser., Vol. IV, 1897, p. 422.

[43] Am. Jour. Sci., 3d ser., Vol. I, 1895, p. 467.

This theory of the igneous origin of the corundum associated with the peridotites is in accord with the field observations, the most important of which are: (1) The occurrence of corundum surrounded by granular peridotite and also by serpentine; (2) its occurrence with and surrounded by spinel; (3) the sharp contact between the gneiss and the alteration products of the border-vein; (4) the same sequence of alteration products which is found on both sides of the corundum-bearing zone of an interior-vein and which is almost identical with that on the peridotite side of a border-vein; (5) the usual thinning and pinching out of the interior-veins, the trend of which is toward the center of the mass of peridotite, while the border-vein seems to extend downward indefinitely.

The laboratory experiments made by Morozewicz[44] and Lagorio[45] to determine the solubility of alumina in a molten basic glass, and the separating out of the corundum and spinel as the first minerals when the glass began to cool, also give strong support to the igneous theory of the origin of the corundum.

Thus the facts obtained in the field and in the laboratory both point to the same conclusions regarding the origin of the corundum associated with the peridotite rocks.

At a number of corundum veins in peridotite rocks, feldspar, which is undoubtedly one of the original minerals of the rock and not a secondary product, is found associated with the corundum. There is a marked difference in the associated minerals when feldspar is present; chlorite is not so abundantly developed and enstatite is less common, while margarite is abundant and zoisite is not uncommon. The last two minerals are rarely seen at corundum veins that are free from feldspar.

The foregoing theory of the separation of alumina from these peridotite magmas has a direct bearing upon the question of origin[46] of several of the associated minerals, spinel, chromite and feldspar in a corundum vein.

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[44] Cited on page 352.

[45] Zeitschr. für Kryst., Vol. XXIV, 1895, p. 285.

[46] Pratt, Am. Jour. Sci., 4th ser., Vol. VIII, 1898, p. 227.

At the various peridotite localities in North Carolina the following associations have been observed:

1. Peridotite rocks containing small particles and grains of chromite, but no corundum or spinel.

2. Peridotites containing deposits of chromite (which upon analysis showed a variable per cent of alumina and magnesia), but no corundum or spinel.

3. Peridotites containing chromite, corundum, and spinel.

4. Peridotites containing chromite and corundum, but no spinel.

5. Peridotites containing corundum and feldspar.

1 and 2. All the chromite analyses that have been examined except two show the presence of alumina and magnesia in varying amounts. In some of them the percentage of alumina and magnesia is very large and where in ordinary chromite the formula may be represented by $9(FeO.Cr_2O_3)$, $(MgO.Cr_2O_3)$, $2(MgO.Al_2O_3)$; at one locality near Webster, Jackson County, a chromite (mitchellite), was found which had the formula $(FeO.Cr_2O_3)$, $(MgO.Cr_2O_3)$, $2(MgO.Al_2O_3)$, as described on page 280. When these rocks contain considerable chromite there is usually no corundum present, or at most but a trace; and when there is but little alumina and only a small excess of magnesia in a peridotite magma containing considerable chromic oxide, it would seem from what has been said above regarding the analyses of chromite, that they unite to form the spinel molecule, which instead of separating out independently as the mineral spinel, enters into combination with the $FeO.Cr_2O_3$ molecule of the mineral chromite (see chapter on Origin of Chromite, page 369).

3. At a few of the peridotite localities both corundum and spinel have been found, as at the Corundum Hill mine, where a fine-grained, almost black spinel occurs, through which is scattered particles and masses of corundum: and at the Carter mine near Democrat, where there is a great abundance of corundum and a green-black spinel. Peridotite magmas of this type, it would seem, contained an excess of magnesia, which united with a portion of the alumina present to form the molecule $MgO.Al_2O_3$, which separated out as spinel. The remaining portion of the alumina formed corundum.

Undoubtedly there is a strong affinity between magnesia and alumina, which tends to form the spinel molecule; but in these peridotite magmas it is only the excess of magnesia over that required for the normal magnesium silicates that has united with the alumina. Except alteration products, there are no alumina-magnesia silicates found in these rocks, showing that in magmas of this type the alumina has no tendency to unite with the magnesia to form double silicates. When, however, the magma is composed largely of calcium-aluminum silicates with but little magnesium, there are developed magnesium-aluminum silicates, as in the troctolites described on page 79.

4. At most of the peridotite localities no spinel at all has been observed, but a considerable quantity of corundum is often found. The chromite at all these localities shows the presence of a certain percentage of alumina and magnesia. Thus the small excess of magnesia unites with a definite amount of alumina, but instead of separating out as spinel, it unites with the chromite, as has been already stated. The remaining and greater part of the alumina separates out as corundum.

5. In a number of these peridotite formations feldspar has been found which is undoubtedly one of the original minerals of the rock and not a secondary product.

At the Buck Creek mine, Clay County, there is, at one of the contact corundum veins, a large amount of feldspar and hornblende which have separated out with the corundum; again, at the Bad Creek mine, Sapphire, Jackson County, the corundum is found associated with feldspar and biotite mica. In both places they are lime-soda feldspars, and this occurrence of feldspar and corundum in a peridotite rock indicates that the molten magma contained some of the alkali and alkali earth oxides, as Na_2O, K_2O and CaO, and that a portion of the alumina united in the formation of the feldspar molecule and that the rest of it separated out as corundum. In a magma of this type there is present a large amount of magnesia which forms the magnesian silicates but apparently has no tendency to unite with the alumina to form spinel; on the other hand the small amount of the alkalies and alkali-earth oxides do unite with a definite amount of the alumina to form feldspar. This, again, would seem to indicate that, in the presence of a certain amount of alkali and alkali-earth oxides and silica, if there is enough silica to unite with these oxides and the magnesia, the magnesia has no tendency to unite with the alumina to form any type of magnesia-alumina minerals.

That the feldspar in these peridotites is contemporaneous with the corundum and not due to its alteration is clearly demonstrated by the examination of specimens showing sharp angular masses and fragments of corundum embedded in the feldspar, and also the intimate mixture of the feldspar and corundum; as well as by the presence of the large feldspar individuals in a ground-mass of the finer grained olivine in the feldspathic peridotites and the troctolites. This is well illustrated in the microscopic sections of Plates XXXVII and XXXVIII, and also by a feldspathic peridotite of eastern Maryland described by Dr. G. H.

Williams,[47] whose investigations are in accord with the conclusions stated above—that the feldspar is older than the olivine and separated out from the still molten magnesian magma. He says:[48] "The structure of these rocks is therefore quite an exceptional one for the family of peridotites; first, on account of the porphyritic character, which is rare in members of this class, and second, because of the unusual position of the olivine in the ground mass, indicating that it is here the youngest instead of the oldest constituent, as is generally the case."

Morozewicz[49] has recently described the formation of corundum from a number of magmas that were supersaturated with alumina. The supersaturated aluminum-silicate magmas had the general composition $MeO.mAl_2O_3.nSiO_2$ ($Me = K_2$, Na_2, Ca, and $n = 2$-13). In these magmas, on cooling, all the excess of alumina (over $m = 1$) separates out in the form of corundum crystals, this taking place when magnesia and iron were not present.

In these experiments the silicates that were used to form the magmas were for the most part those of calcium, sodium, and potassium. When alumina was present in them in excess of $m = 1$, it would separate out in the form of corundum; but when the magma was not saturated with alumina or m was equal to 1 or less, all the alumina was used up in the formation of double silicates. When magnesia was present, the excess of alumina united with the magnesia to form the mineral spinel, and if not enough magnesia was present to unite with all of the alumina, some corundum was formed. When there was an excess of silica, or n was greater than 6, the excess of alumina united with the silica to form the mineral sillimanite and the over excess of alumina separated out as corundum. When, however, magnesia and iron were present with the excess of silica and alumina, cordierite and spinel were the minerals formed.

From these experiments it would seem that, where a magma is composed of silicates of the alkali and alkali-earth metals, sodium, potassium, and calcium, the alumina dissolved in this magma will to a certain point unite to form double silicates of alumina with these other bases; but when the ratio of alumina to these bases is greater than 1, the excess of alumina will separate out as corundum except when influenced as just described. Magnesia, it would seem, does not have so strong an affinity for silica, and when present in the magmas, influences the separation of alumina as an aluminate of magnesium, i. e., in the formation of the mineral spinel, or if there is an excess of both alumina and silica in the presence of iron, in the formation of the mineral cordierite.

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[47] Bull. U. S. Geol. Survey No. 28.

[48] Ibid., p. 53.

[49] Tschermak's Min. u. Petrogr. Mittheilungen, Vol. XVIII, 1898, pp. 1-90 and 105-240.

In some earlier experiments, Morozewicz[50] has shown that alumina will readily dissolve in a molten magma having a composition approximately that of the basic magnesian rocks, and that upon cooling the alumina separates out as corundum and spinel.

The alumina and the magnesia seem to have but little tendency to unite to form double silicates except where the magma contains but little magnesia and some iron, when the mineral cordierite is formed; nor do these unite to form the mineral spinel ($MgO.Al_2O_3$), except when there is an excess of MgO, when some spinel is formed; but the greater portion of alumina separates as corundum. This would seem to show that the affinity of magnesium for silica to form a silicate is stronger than for alumina to form an aluminate.

SUMMARY.

From what has been observed in nature and from experiments that have been made in the laboratory, it seems that the separation of alumina as corundum from molten magmas is dependent upon the composition of the chemical compounds that are the bases of the magmas, upon the oxides that are dissolved with the alumina in the magma, and upon the amount of alumina itself.

1. When the magma is a calcium-sodium-potassium silicate, no alumina held in solution by such a magma will separate out as corundum except when the ratio of the alumina to the other bases is more than 1:1 and the ratio of the silica is less than 6.

2. If magnesia and iron are present in the above magma, corundum will not form unless there is more than enough alumina to unite with the magnesia and iron.

3. When the magma is a magnesium silicate without excess of magnesia, *all* the alumina held by such a magma will separate out as corundum.

4. Where the magma is a magnesium silicate with excess of magnesia, this excess will unite with a portion of the alumina to form spinel and the rest of the alumina, if any remains, will separate out as corundum.

5. Where there is chromic oxide present in a magma composed essentially of a magnesium silicate (as the peridotite rocks) and only a very little alumina and magnesia are present, these, uniting, separate out with chromic oxide to form the mineral chromite and no corundum or spinel is formed.

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[50] Zeitschr. für Kryst., Vol. XXIV, p. 281, 1895.

6. When peridotite magmas contain, besides the alumina, oxides of the alkalies and alkali-earths, as soda, potash, and lime, a portion of the alumina is used in uniting with these oxides and silica to form feldspar.

7. The alumina and the alkali and alkali-earth oxides have a strong tendency to unite to form double silicates like feldspars, whether such silicates form the chief minerals of the resulting rock or are present only in relatively small amount; but the alumina has little tendency to unite with magnesia to form double silicates when the magma is a magnesium silicate.

In the following table these phenomena have been summarized in a way that perhaps makes the various results stand out more prominently.

Table showing separation of alumina from molten magmas.

Magma silicates.	Dissolved oxides.	Minerals formed.
Ca — Na — K. Silicates.	$Al_2O_3 : R$[51] $> 1 : 1$	Corundum.
	+ excess SiO_2	Sillimanite.
	Al_2O_3, MgO, FeO	Spinel.
	+ excess Al_2O_3	Corundum.
	+ excess SiO_2	Cordierite.
(Mg, Fe) Si O_4	Al_2O_3 No excess MgO	Corundum.
	Al_2O_3	
	+ excess MgO	Spinel.
	+ excess Al_2O_3	Corundum.
	Al_2O_3, Cr_2O_3 No excess MgO	Corundum. Chromite.
	Al_2O_3, Cr_2O_3	Corundum. Picotite.
	+ excess MgO	Mitchellite. Chromite.
	CaO, Na_2O, Al_2O_3, SiO_2	Plagioclase feldspar.
	+ excess Al_2O_3	Corundum.

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[51] R = other bases.

Of the igneous magmas here considered, there are two which are very distinct from each other and which may be designated as the alkaline series and the lime-magnesia series. The rocks derived from the latter are free from alumina, and where this oxide has been held in solution in the molten magma it has all separated out either as corundum or spinel. In the rocks of the first series, however, it is only the excess of alumina that has separated out as corundum, by far the larger percentage having united with the alkaline oxides to form feldspar. In all the occurrences that have been examined, these phenomena have been constant.

It is very evident that there are magmas that contain an excess of alumina, just as there are magmas that contain an excess of silica, and that the alumina separates out as corundum according to the same laws that govern the separation of silica as quartz in granitic rocks, but not at the same period in the order of crystallization.

The same general laws, given above, will apply to the separation of the alumina as corundum in the amphibolites and pyroxenites when they were in a molten condition. As they occur for the most part in narrow dike-like formations instead of lenticular masses, particularly the amphibolites, consolidation would be so rapid that the corundum would be generally distributed through them rather than concentrated along their borders.

ORIGIN OF CORUNDUM IN AMPHIBOLE-SCHIST OF MACON COUNTY.

The occurrence of corundum in the amphibole-schist of Cowee Valley, Macon County, has been described in detail on page 217. The rock is composed chiefly of labradorite, amphibole, and garnet, with staurolite and rutile, muscovite and biotite as accessory minerals. The labradorite of this rock is often broken, exhibits rolling extinctions, and the albite lamellæ are curved and bent, strongly indicating a shearing movement in the rock. The corundum does not occur in crystals but in small fragments and in elongated nodules, which are cracked and seamed as if they had been drawn out during the shearing process. The staurolite is in rather broad irregular grains, and the rutile is in small irregular grains and well crystallized prisms.

The character and structure of this rock indicate that it is a metamorphosed igneous rock of the gabbroid family. During metamorphism the augite of the gabbro would be converted into the brown hornblende. Any iron ore that was present would be taken up by the hornblende and garnet. The rutile would have resulted from the titanic acid that is a regular component of the iron ores in such gabbro or diabase rocks. Staurolite is usually a product of metamorphism, and its natural home is in the schistose rocks. Chemically the feldspar has suffered the least (except the corundum), and shows only the shearing of dynamic processes. The general character and shape of the corundum would indicate that it was an original constituent of the igneous rock, and not formed during its metamorphism.

ORIGIN OF CORUNDUM IN QUARTZ-SCHIST OF CLAY COUNTY.

These rocks which are found in Clay County, N. C., and Rabun County, Ga., are described at length on pages 215, 216. They vary from a normal gneiss to rocks that contain little or no feldspar and can be best designated as quartz-schist.

Portions or bands of these schists are corundum-bearing, but they are irregularly defined and gradually merge into the normal rock. Their relation to the normal schists is similar to that which the garnet-bearing bands of a gneiss bear to the normal gneiss in which they occur. They are not veins in any sense of the word, but are simply portions of the mass of crystalline rock, the corundum occuring as a constituent of the rock.

These bands can be traced for a distance of 5 or 6 miles in a N.E.-S.W. direction, sometimes outcropping continuously for nearly a mile. The only variation that has been observed in them is in the percentage of corundum and garnet; otherwise they are identical. The corundum occurs for the most part in small particles and fragments that have no definite shape and vary from a gray, white, and bluish-white color to almost colorless. It is also in crystals, ranging from minute ones to some that are 2½ inches long and about one-half an inch in diameter, which are usually fairly well developed in the prismatic zone.

As pointed out in Chapter I, there are evidences, such as the presence of graphite and limestone, that indicate a sedimentary origin for many of the gneisses and schists of this region. It is probable that these schists are the result of the metamorphism of sandstones and shales that were formed, perhaps many thousand feet in thickness, on the bed of the ancient seaborder. By lateral compression these have been folded and raised into the mountain ranges of this section; and at the same time they were metamorphosed into crystalline schists and gneisses. That these ranges were once much higher than they are now is very evident from the granitic areas now exposed, which are of deep-seated origin. By decomposition and erosion the mountains have been worn down to their present condition, thus exposing the schists in contact with the granitic masses that may have aided in their metamorphism. Some of the strata were rich in alumina, which not improbably was in the form of bauxite, and during their metamorphism the excess of alumina crystallized out as corundum. This mineral has crystallized out along the planes of lamination, so that during the subsequent weathering of the rock the corundum has been left in nodules, studding the surface of the rock and giving it the appearance of containing a high percentage of this mineral.

This view of the conversion of rich aluminous deposits into corundum is strengthened by the experiments made in the artificial production of corundum from bauxite by means of very great heat and pressure in an electrical furnace, as described on page 338.

CHAPTER XI.

CORUNDUM MINING AND MILLING.

HISTORICAL SKETCH.

CORUNDUM IN THE EAST.

Just how early in history corundum was known has not been determined, but the very earliest records show that the ancients were familiar with the corundum gems ruby and sapphire. Nothing, however, was known of corundum as an abrasive until recent years, although some have been led to the belief that the ancient Egyptians were familiar with the use of emery, from the perfection of the engravings on their monuments; for the islands of the Grecian Archipelago, which contain large quantities of emery, were accessible to them.

The early Greeks and Romans were familiar with the ruby and sapphire and had made considerable investigation into the physical properties of these gems, and had also described their mode of occurrence.

The first known deposits of corundum in quantity that would be of value as an abrasive were those of the emery fields of the islands of the Grecian Archipelago, and up to 1847 all the corundum used as an abrasive was obtained from these islands, principally from the Island of Naxos. In that year, Dr. J. Lawrence Smith, the American pioneer in corundum mining, in the employ of the Turkish government, discovered important emery deposits in Asia Minor. The importance of this discovery was clearly realized when in 1850, on account of the working of these deposits the price of emery dropped from $140.00 to $70.00 and $50.00 a ton. Since that time both the Turkish and Grecian emeries have been mined and exported.

In India, besides the deposits of gem corundum, there have been known for many years various localities where corundum has been found that was not of the sapphire variety, but it is only within the past few years that these deposits have been developed and the corundum has been mined and exported for abrasive purposes.

AMERICAN CORUNDUM.

So far as can be learned from the literature on the subject, corundum was not known in America before 1819. In that year, Mr. John Dickson, a teacher, of Columbia, South Carolina, sent Prof. Silliman a lot of minerals which he had collected on a tour through the Carolinas. Among these there was a regular six-sided crystal of blue corundum three-fourths of an inch long and one inch in diameter, with parting striæ developed similar to the East Indian corundum. It was sent without label, and in reply to an inquiry as to its locality, Mr. Dickson wrote:[1] "I think it was Laurens district; at all events, it was picked up by my own hands, if not in situ, in a place * * * which it could have reached only by one of the usual and natural accidents which displace minerals of all kinds * * * I am sure it is American and Carolinian."

In 1822, both Edward Hitchcock[2] and Parker Cleaveland[2] described a mass of cyanite found at Litchfield, Conn., "associated with talc, sulphuret of iron, and corundum * * * supposed to weigh 1500 pounds." The corundum was massive and in six-sided prisms, of a dark grayish blue color, and imbedded in cyanite. Both of these authors attribute their information to Mr. John P. Brace.

In 1825 Samuel Robinson[3] mentioned corundum in the list of minerals occurring in the vicinity of Franklin, N. J.

In April, 1827, at a meeting of the Lyceum of Natural History, New York, "Major Delafield[4] * * * exhibited crystals of Sapphire from Newton, Sussex County, New Jersey." In 1832, Dr. Fowler[5] described this locality, pointing out the geologic and mineralogic relations of the corundum. It is found along the border of crystalline limestone.

According to Mr. W. W. Jeffries, as quoted by Mr. Joseph Willcox, Messrs. John and Joel Baily claim to have discovered corundum in the serpentine region of Chester County, Pennsylvania, about 1822 to 1825. Dr. Thomas Seal collected specimens at Unionville about 1832, and Mr. Jeffries himself saw large lumps in the fields there in 1837 or 1838.[6] A ton of surface fragments and boulders was collected about 1839 and shipped to Liverpool. But the search for the source of this material was unsuccessful till 1875, when a large lenticular mass was found in place. This consisted chiefly of corundum and margarite and carried some fine specimens of diaspore.[7]

In 1837, Prof. J. D. Dana,[8] after describing the occurrence at Newton,

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[1] Am. Jour. Sci., 1st ser., Vol. III, 1821, pp. 4, 229, 230.

[2] Am. Jour. Sci., 1st ser., Vol. VI, 1823, p. 219; Cleaveland's Mineralogy and Geology, Boston, 1822.

[3] A catalogue of American Minerals and their localities, Boston, 1825, p. 165.

[4] Am. Jour. Sci., 1st ser., Vol. XIII, 1828, p. 380.

[5] Am. Jour. Sci., 1st ser., Vol. XXI, 1832, pp. 319, 320.

[6] Second Geol. Survey Pennsylvania, C 4, 1883, pp. 346, 351.

[7] Second Geol. Survey Pennsylvania, B, 1875, pp. 31-33.

[8] System of Mineralogy, 1st ed., 1837, p. 330.

N. J., says that "well-defined crystals of a bluish and pink color are found in a similar situation at Warwick, N. Y." Professor Dana further states that "isolated crystals have been found imbedded in the soil in North Carolina," but this probably refers to the specimen found by Mr. Dickson in South Carolina, the names of the states being confused.

In a report on the Mineralogy of New York, in 1842, Dr. Lewis C. Beck mentions the occurrence of corundum in the white limestone near Amity, in Orange County.

The first discovery in North Carolina was a large detached block of dark blue, laminated corundum, found on the French Broad River, 3 miles below Marshall, in Madison County, in the spring of 1847.[9] Gen. T. C. Clingman, after considerable search, found another piece in the same vicinity in 1848, about a year before the first discovery of emery in place in Asia Minor by Dr. J. L. Smith.

In 1852 appeared the first authenticated record of the occurrence of corundum in Georgia,[10] when Mr. Plant, a banker of Macon, Georgia, sent a ruby crystal to Prof. Shepard, at Amherst. This, like others, had been found in washing for gold.

In 1852, Mr. W. P. Blake[11] described corundum from the new locality at Vernon, Sussex County, New Jersey. In the spring of the same year, Dr. C. L. Hunter[12] discovered corundum and emery in place in Gaston County, North Carolina.

The first record of the occurrence of corundum in Canada is in 1863. In the report of the Geological Survey of Canada for this year, p. 499, it describes the occurrence of corundum in and closely associated with the limestone of Burgess.

In 1864, the occurrence of emery at Chester, Massachusetts, was predicted by Dr. C. T. Jackson from his discovery there of margarite, a mineral which Dr. J. L. Smith had just found characteristic of the emery deposits of Asia Minor. On September 6 of the same year, Dr. H. S. Lucas[13] discovered the emery in what had before been considered only deposits of magnetic iron ore. Two years later, distinct crystals of corundum were found in the same deposits.[14] This discovery of emery soon led to active mining, the first of its kind in America. This mine is still worked, and though it has not been operated continuously from the beginning, it is still the main producer of corundum in this country.

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[9] Bull. U. S. Geol. Survey No. 74, 1891, pp. 293-301.

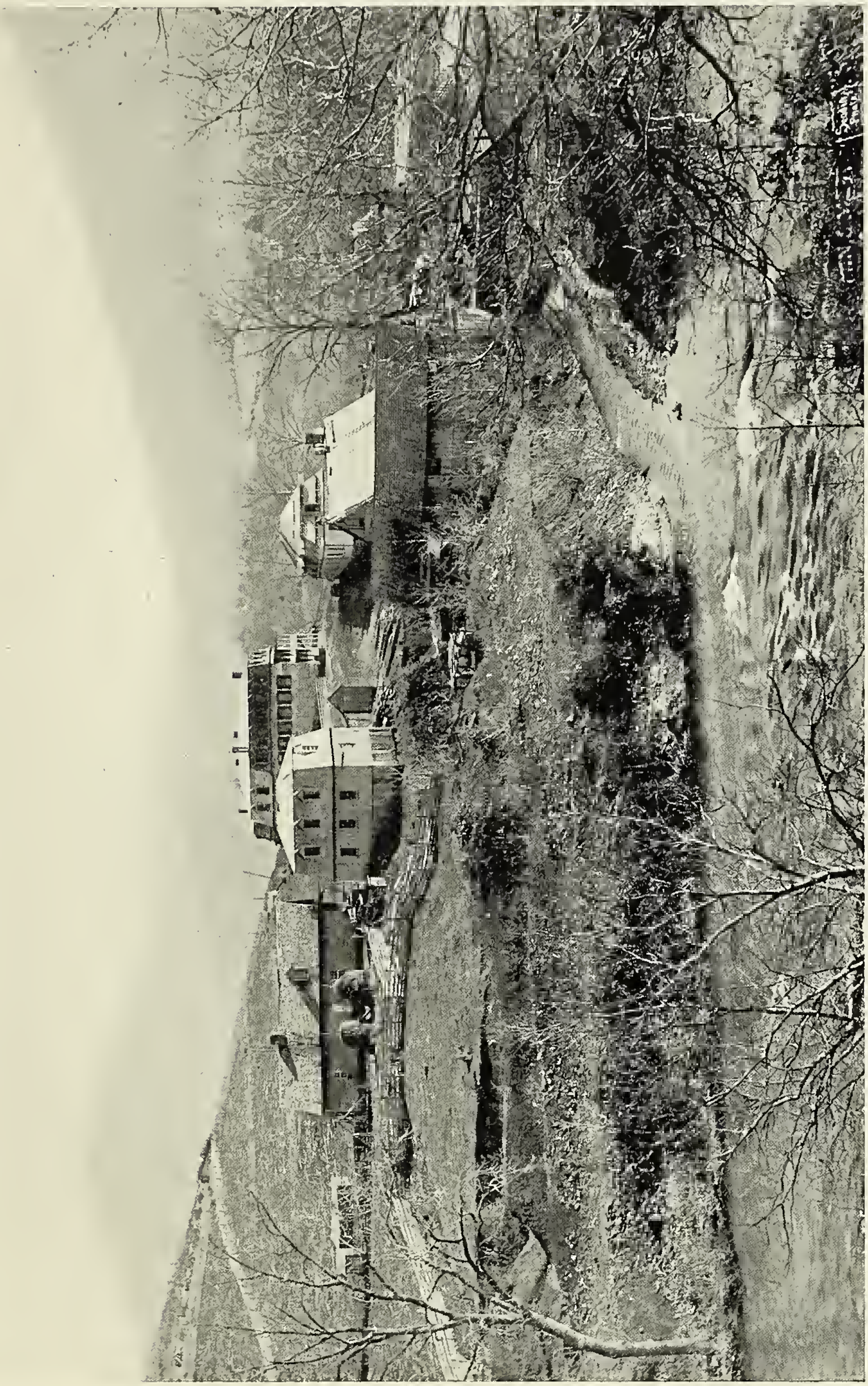
[10] Am. Jour. Sci., 3d ser., Vol. IV, 1872, p. 109, and Bull. Geol. Survey Georgia, No. 2, 1894, p. 18.

[11] Am. Jour. Sci., 2d ser., Vol. XIII, 1852, p. 116.

[12] Am. Jour. Sci., 2d ser., Vol. XV, 1853, p. 376.

[13] The exact date was furnished by Dr. Lucas.

[14] Am. Jour. Sci., 2d ser., Vol. XXXIX, 1865, pp. 87-90; Vol. XLII, 1866, p. 421.



CORUNDUM HILL (CULLASAJA), MACON COUNTY, N. C., SHOWING MILL AND STORE BELONGING TO MINE.

In 1870, Mr. Hiram Crisp found the first corundum that attracted attention to the present mining region of North Carolina, at what is now the Corundum Hill mine (Pl. XXV). A specimen was sent to Prof. Kerr, then State Geologist, for identification, and considerable interest was aroused when it was discovered that it was corundum. In the same year, Mr. J. H. Adams[15] found corundum in a similar occurrence at Pelham, Massachusetts.

In 1870-71, much activity was displayed in the search for corundum in the peridotite regions of the southwestern counties of North Carolina, and new localities were soon brought to light in Macon, Jackson, Buncombe, and Yancey counties. In 1871, Dr. Genth[16] discovered the emery of Guilford County. About this time, Mr. Crisp and Dr. C. D. Smith began active work on the Corundum Hill property, and obtained about a thousand pounds of corundum, part of which was sold to collectors for cabinet specimens. Some of the masses that were found weighed as much as 40 pounds.

Systematic mining for corundum did not begin until the fall of 1871, when the Corundum Hill property (Pl. XXXII) was purchased by Col. Chas. W. Jenks, of St. Louis, Missouri, and Mr. E. B. Ward, of Detroit, Michigan, and work was soon begun under the superintendence of Col. Jenks. This was the first systematic mining of common corundum. as distinguished from emery and the gem varieties, ever undertaken, while the first mining of the emery variety of corundum in America was at Chester, Massachusetts.

In the following spring (1872) the Laurel Creek or Pine Mountain mine, in Rabun County, Georgia, was opened by Col. Jenks, which was the beginning of corundum mining in Georgia, although about 1870, at nearly the same time that corundum was first found at Laurel Creek, Mr. William R. McConnell, of Hiwassee, Towns County, had obtained a considerable quantity of surface corundum on his estate. In the spring of 1875 both the Corundum Hill and Laurel Creek mines passed into the hands of Dr. H. S. Lucas, of Chester, Massachusetts, who for many years was the main promoter in extending the corundum industry.

These two localities, Corundum Hill and Laurel Creek, continued to furnish the world's supply of corundum (except emery) until 1893, when mining was discontinued at Laurel Creek, and since then, until very recently, the Corundum Hill mine has been the chief producer.

In 1874 or 1875, corundum was discovered near Statesville, in Iredell

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[15] Am. Jour. Sci., 2d ser., Vol. XLIX, 1870, p. 271.

[16] Rept. Geol. Survey North Carolina, Vol. I, 1875, p. 246.

County. In a letter in regard to this Mr. J. A. D. Stephenson writes: "The first corundum found in Iredell County was found by myself near where the Collins (Acme) mine is now located, either late in 1874 or early in 1875. It was a mass weighing probably two pounds. I also found a lot of pink fragments near by." Soon afterwards it was discovered on the surface at many other points in this county and in Alexander, the adjoining county on the west.

Since these early discoveries prospecting for corundum has been carried on vigorously in the peridotite belt of Georgia and North Carolina, and many deposits have been located, but many of them, being almost inaccessible, have been but little developed.

Until the year 1898 the corundum deposits of Georgia and North Carolina furnished all the corundum (exclusive of emery) used in this country, with the exception of a very small amount obtained from Pennsylvania. Many localities throughout the eastern States were prospected for corundum, and at a number of places in Alabama, South Carolina, Pennsylvania, and Massachusetts mining on a small scale was undertaken, and although in most cases a little corundum was shipped none of these localities developed mines of this mineral.

In 1899, mining was begun on the corundum deposits in Ontario, Canada (p. 223), and these have since become one of the chief producers of this mineral in America.

Work on the Montana corundum deposits (p. 222) began in 1900 and they are now in such a condition that their product can be shipped in competition with that from other localities.

The latest discovery of corundum in America is in Plumas County, California (p. 223). It was prospected to some extent in 1901 but no commercial quantities of corundum were located.

SUGGESTIONS TO PROSPECTORS.

Most of the early discoveries of corundum were made, as were those of many of the other minerals, by the accidental finding of surface fragments. This has led to systematic search, which in many cases has resulted in the location of extended deposits. Not only corundum itself but many other minerals that are associated with it are important indicators of the existence of corundum. Thus the presence of margarite at the old iron mine at Chester, Massachusetts, was to Prof. A. T. Jackson, who was familiar with its occurrence, an indication that corundum would be found. His prediction was realized a short time afterwards by the finding of the emery variety of corundum and the conversion of the iron mine into an extensive emery mine. The finding of chlorite in connection with peridotite rocks has been the starting point of the discovery of a number of corundum deposits.

Any one who wishes to search for corundum should thoroughly familiarize himself with the mineral itself as well as its associates, for many instances could be cited where other minerals have been mistaken for it. Thus the mineral albite, one of the feldspars, is sometimes very similar in appearance to corundum, and has been mistaken for it, but the specific gravity and hardness should at once distinguish it from corundum, the albite being much lighter and softer. It is well in prospecting for corundum to always have a specimen of the pure mineral at hand with which to test the hardness of any mineral that may be supposed to be corundum.

In testing the hardness of a mineral care should be taken that all decomposed and altered material is broken away and that the test is made on a clean surface of the pure mineral.

Where it is possible the prospector should visit either a corundum mine, or a locality where prospecting has been done and corundum found in place, and thus become acquainted with the rocks enclosing it and its mode of occurrence. As has been shown in the preceding pages, no two localities are often exactly duplicates even when they are close together, yet certain minerals and types of rocks are found at nearly all of them, and familiarity with these, even at one locality, will be of considerable value to one who is searching for new localities.

Nearly all of the corundum that has thus far been found in quantity in North Carolina is that which occurs in peridotites, and consequently most of the prospecting that has been done in this State has been in connection with these rocks. It is not to be understood that corundum may not occur in quantity in any other rocks than the peridotites in this State, but that, although corundum has been found in a number of other rocks besides these and at a number of localities, it has not yet been demonstrated that these deposits can be profitably mined. Some of the occurrences in amphibolites and gneisses have given promise of becoming of commercial importance, but only actual development can prove or disprove this. This does not, however, apply to gem-corundum deposits but only to those where the corundum is wanted in quantity for an abrasive.

It is not only essential to have a knowledge of the rocks in which it occurs but also a knowledge of the associated minerals. This is especially true of the corundum found in the peridotites, although not all these rocks in the State carry corundum and the associated minerals are likely to vary with the locality.

Under the head of Origin of Corundum (p. 334), it is shown that the deposits of corundum in the peridotites occur chiefly near their contact with the gneiss or other country rock, and that the deposits within the peridotite area are usually small and in a short distance pinch out. Hence, in prospecting over a peridotite area, a careful systematic search should be made along the contact. Corundum may often be first observed within the peridotite area, and when this is the case, a larger deposit may very reasonably be expected to be found near the contact.

If during an examination of a peridotite formation, no corundum is found along the contact of this rock with the gneiss or other country rock, there is no need of searching in the midst of the formation, for experience has shown that it is only at the contact that any large deposit will be found. Again, if no fragments of corundum are found at the lower borders of a peridotite formation or none can be obtained by panning the gravel of the streams flowing by them, there is but little probability that success will attend any further search. It should also be borne in mind that at all the peridotite localities examined, no more than traces of corundum have been found where there is a quantity of chromite, and, on the other hand, where there is much corundum there is a scarcity of chromite.

Where crystals and fragments of corundum are found in gravel beds or in the soil, they of course indicate the existence of corundum deposits at some distance from where these occur. On account of the stability of this mineral when exposed on the surface, it may have been transported long distances down the mountain slopes without showing much alteration or abrasion. When, however, it is associated with certain minerals, as fragments of chrysolite (olivine), chlorite, or talc, it is very probable that they have been transported but a short distance, for these minerals would have been almost entirely disintegrated and worn away before they could have been transported very far or exposed very long to surface influences.

Where corundum has been thus found, these indications should be followed up the valley or incline by which the fragments most naturally have reached their present position. When followed up, these gravel deposits, whether they are in the present or old beds of the streams, should be tested at intervals by panning (see Pl. XXII), until a point is reached beyond which no corundum is found in the gravel, and then the search should be carried on up the hillsides till the parent rock is located. If this rock is a peridotite, its contact with the other country rock should be carefully examined, for it is here that the deposits of corundum should be expected. Where there is considerable soil or decomposed surface material, the contact cannot always be at once located, and then ditches should be cut through the soil at right angles to the strike of the rock itself. When the contact has been found, the border zones of the minerals should be examined for corundum. A guide at this point is found in the chlorites and vermiculites that have always been observed surrounding corundum at the contact of a peridotite with a gneiss or other country rock.

Where chlorite and vermiculite are found abundantly on the surface, even though no corundum is associated with them, it may sometimes be advisable to trace these to their original source, but this will depend upon the character of the rocks in the vicinity and the general geology of the region in which they are found. No matter how promising the indications may be, they should always be regarded as only probabilities; and no investments should be made until the deposit itself has been thoroughly investigated.

METHODS OF MINING.

In considering the methods used in mining corundum it must be borne in mind that up to 1899 it had been obtained in quantity only where it had been associated with peridotites. These, as will be shown later, present certain difficulties which, if not guarded against, will cause considerable delay and danger in mining, and which would not be met with if the corundum mined were in a gneiss, syenite, or an amphibolite.

Nearly all of the peridotite formations in which the corundum deposits occur are bold outcrops on mountain sides and hill tops, with an almost perfect natural drainage. At all of the localities where there has been any mining, beyond a little prospecting, the method employed has been usually by means of open cuts supplemented by tunnels (see Pls. XXIII, XXVII, and XXVIII). While the mining by means of cuts may seem at first to be the most advantageous, it is soon found that it is the cause of considerable extra expense. These cuts, or any other openings made over the surface of the peridotite, afford a much greater opportunity for surface water and frost to penetrate the mass of the rock formation. These rocks, which are more or less seamed or cracked, usually to the depth that alteration can extend, offer opportunities for the infiltration of the water. As most of the alteration products of the peridotites are slippery hydrous magnesium minerals, as serpentine, talc, and chlorite, and as these are developed in the seams and cracks of the rock, anything that is done to disturb this altered surface will make them very liable to slip. For instance, at the Corundum Hill mine large masses of peridotite have become loosened and, slipping, have gradually closed up some of the tunnels; and there is continual danger, in the cuts and some of the tunnels, from large fragments of rock that it is practically impossible to keep from falling in. At the Laurel Creek mine, Pine Mountain, Georgia, a mass of peridotite with soil, etc., forming nearly a 200-foot cube, has, on account of open cuts beneath it, become loosened and slipped downward, effectually closing up the tunnel and shaft of the Big Vein.

It is, therefore, by all means advisable, in mining corundum associated with peridotites, not to break the surface of the formation any more than is absolutely necessary, and to do no work at all along the contact by means of open cuts, but to confine the mining to a system of tunnels and shafts. This method of mining will be found in the end the cheapest. Then again, all the tunnels and shafts should be well timbered, and the mine should be kept as thoroughly drained as possible.

Considerable work is often done without any mining. A large amount of the material that it is necessary to handle is easily worked with pick and shovel, as it consists of the crystals and fragments of corundum in the zone of chlorite and vermiculite. In some of the veins, such as those in which the corundum is associated with feldspar, as at Buck Creek, and those where there is considerable amphibole or enstatite, as at Corundum Hill, blasting is necessary. Most of the corundum deposits in peridotite are so located that there should be little hoisting necessary for some time. By drifting from a shaft sunk at the upper end of a tunnel that has been run into the vein at the lowest level possible the ore can be removed with a minimum of hoisting and the mine will be kept dry.

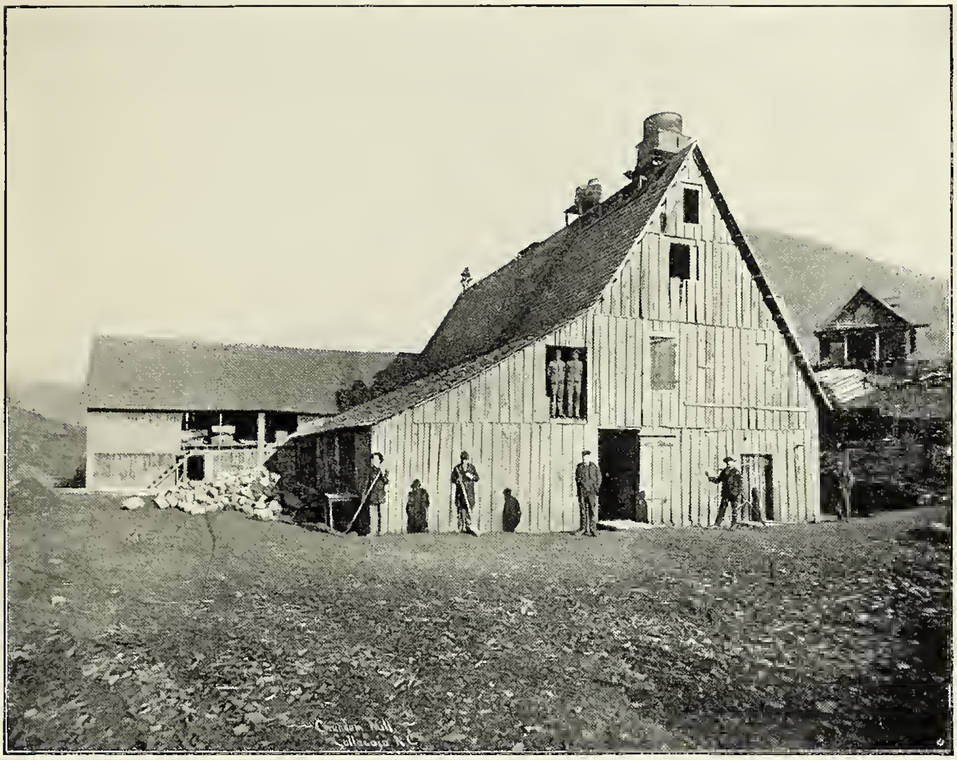
If the mill is located some distance from the mine and a line of sluice boxes can be built, the more or less finely divided ore may be carried to it by means of these. In this way, the corundum is partially cleaned by the time it reaches the mill. This is the method employed at the Corundum Hill mine.

Where the corundum occurs in a gneiss, quartz-schist, or syenite, there should be no difficulty in mining by means of open cuts if the deposit is favorably situated, and these rocks will make good retaining walls, requiring but little timbering.

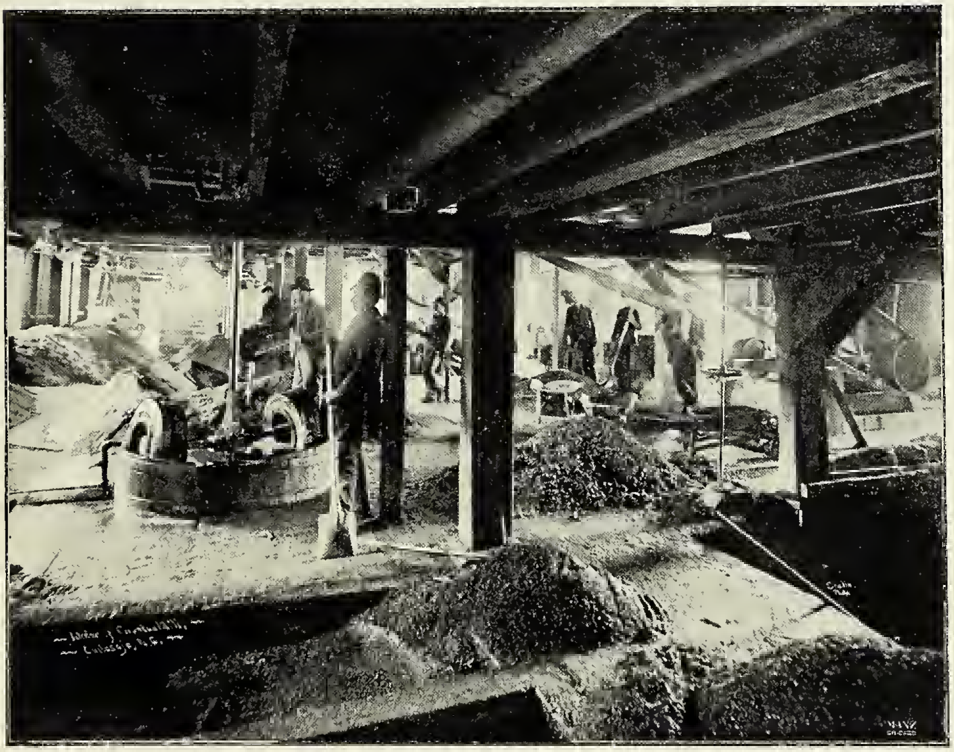
The ore, when removed from the mine, may be carried to the mill either in sluice troughs, in wagons, or cars, according to its nature and the relative location of mine and mill.

METHODS OF MILLING.

The corundum ore as it comes from the mine contains considerable amounts of impurities, which must be removed before the material can



A, EXTERIOR VIEW OF MILL AT CULLASAJA, MACON COUNTY, N. C.



B, INTERIOR VIEW OF SAME.

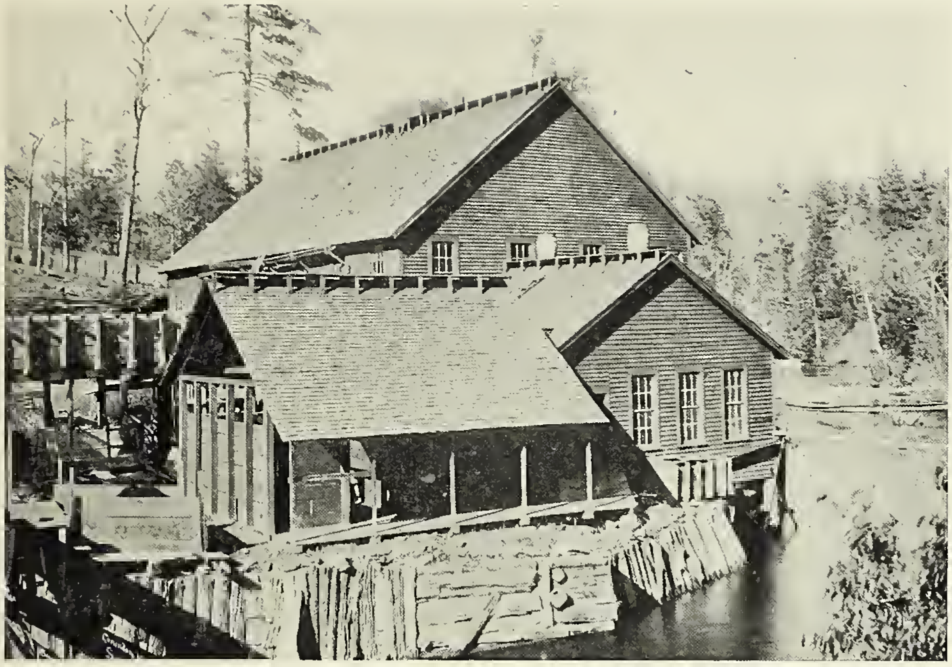
be marketed, necessitating extensive cleaning plants or corundum mills (see Pl. XXXIII, A and Pl. XXXIV, A and B). The removal of most of these impurities is readily effected by conveying the crushed ore into boxes or troughs through which a stream of water runs, and which are so regulated that the corundum readily settles to the bottom of the trough while the lighter minerals are carried off. Before this washing, the corundum ore is sieved and all that will not pass through a No. 12 screen is crushed and passed between rollers until it is reduced to a size that will permit it to pass through the screen. This washing process will remove only the impurities that are entirely separated from the particles of corundum, but there are usually some that are attached, and these have to be removed by another process. The product is passed through a machine known as the screw or scouring machine, in which there is a coarse worm similar to screw conveyer. This grinds off almost all of the impurities and these are separated by subjecting them again to the washing process. The final impurities are separated from the particles of corundum by means of a machine called the "muller" or "chaser." In this machine the grains of corundum are rubbed one against another and thus wear away adhering foreign substances. The machine consists of a shallow tub, in which are two heavy wooden rollers which move around its circumference. The freshly ground corundum on being thrown into these tubs is kept constantly stirred up and then pressed down by the rollers passing over it, and in this way a scouring motion is kept up between the grains, by which the impurities are gradually worn away, and carried off by a stream of water which is flowing through the tub, coming in at the bottom and passing out at the top. The corundum in the tub is kept stirred up by men with hoes or by having iron plow-shaped blades in front of the wooden rollers; and it usually requires from four to eight hours, according to the nature of the impurities that are attached to the corundum grains, to obtain a clean product. Plate XXXIII, B is an interior view of the corundum mill at Cullasaja showing a "muller" in the foreground.

There are two methods of drying this product after it has been removed from the mullers and allowed to lie over night on an inclined floor. In one this product is conveyed by elevator belts to the second floor of the mill and dropped vertically a distance of 20 to 30 feet down the stack of a furnace, at the bottom of which it strikes an inclined surface that is just above the flames of the furnace, and slides down this into an iron box. In the other, there is an iron cylinder, open at both ends, which revolves about a coil of steam pipes. One end of the cylinder is lower than the other and as the wet product is thrown in at the upper end, it is alternately carried up by the revolving cylinder and dropped on the hot coil of pipes and is gradually worked toward the lower end, where it is caught in a hopper, and conveyed by elevator belts to the sizing room. Here it is automatically screened to the various sizes.

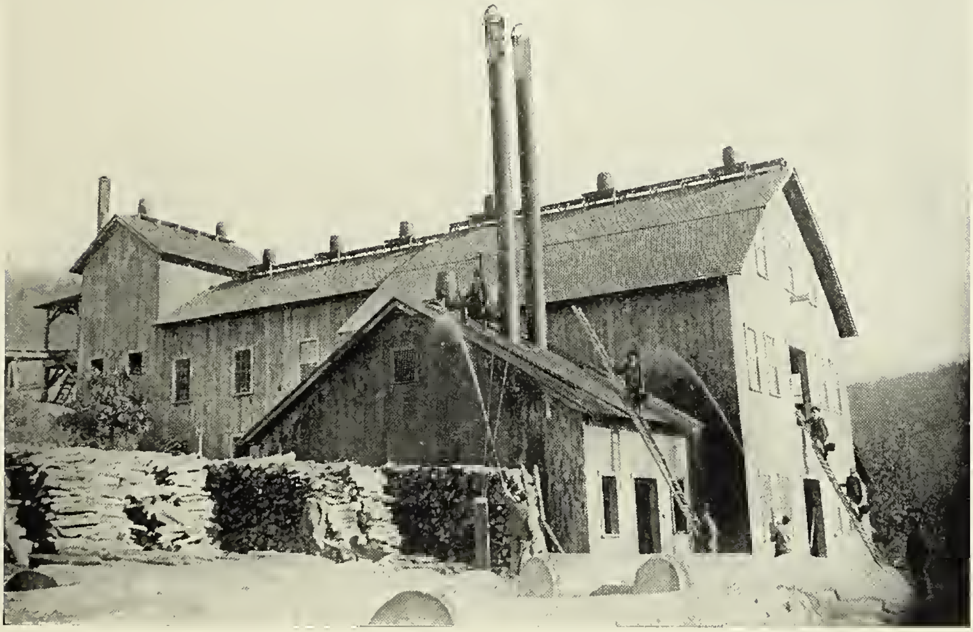
Care has to be exercised in the crushing of the ore, so as to produce as little flour-corundum as possible. Also, in the scouring action that is carried on in the mullers, the process must be made as short as possible, in order to prevent the corundum grains from becoming rounded so as to destroy their abrasive qualities.

While the general principle of cleaning the ore is the same at nearly all the mills, and the process is carried out in the same order, yet there are several different methods for effecting a separation of the grains of corundum from the impurities that are not attached to them. Owing to the high specific gravity of corundum, this can be readily done, and various machines have been devised for the purpose.

At the Isbel mine, Shooting Creek, Clay County, the concentrating plant of the corundum mill is equipped with jigs and Frue rammers. The use of these machines does not eliminate the foreign material that is attached to the particles of corundum, and these must be removed by some scouring action as mentioned above. In some instances, a very high grade and pure concentrate can be obtained by the above method of concentration and there is no need of further purification to make a commercial product. Nearly all of the corundum, however, that occurs in the peridotite rocks requires some other treatment besides that of ordinary concentration to make a commercial product. Exceptions to this are the occurrences of large quantities of massive block corundum.



A, CORUNDUM MILL AT SAPPHIRE, JACKSON COUNTY, N. C.



B, CORUNDUM MILL AT BUCK CREEK, CLAY COUNTY, N. C.

CHAPTER XII.

CHROMITE AND OTHER ECONOMIC MINERALS OF THE CORUNDUM-PERIDOTITE BELT.

Besides corundum a number of other minerals of economic importance are associated with the peridotites. Of these but one, chromite, has thus far been found in quantity. Others that are of less importance, but that have attracted considerable attention, are asbestos and genthite (nickel silicate). As these are directly associated with the peridotites and as some deposits of these minerals promise to become commercially important, a brief description of them is given here. The peridotite has been thoroughly altered to serpentine at a number of localities and at some of these the indications are commercially favorable. These localities are described below.

CHROMITE.

OCCURRENCE AND ORIGIN.[1]

Chromite has been found in place only in peridotites and allied igneous basic magnesian rocks, or in serpentines that have resulted from the alteration of these. It occurs also in alluvial deposits that are composed in part of fragments of these rocks. In the North Carolina peridotites, chromite occurs commonly in grains or crystals, but also in embedded masses, near the boundary of the lenticular bodies of these rocks. It does not occur in well-defined veins, but is often in masses or pockets, which apparently have no relation whatever to one another.

Few authors who have written upon the occurrence of chromite have described the relation of the chromite deposit to the rocks in which it occurs. One or two have mentioned the fact that the chromite is found near the eastern boundary or at the northern border of the serpentine belt, but in no case has any definite description been given. The large deposits of chromite in North Carolina occur in peridotite, near the contact of this rock with the inclosing gneiss; and where there is but a small amount of the chromite, either in pockets or in grains or crystals, these are more abundant near the contact and diminish in number toward the center of the mass of peridotite.

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[1] Glenn, Am. Inst. Min. Eng., Vol. XXV, 1895, p. 465; and Pratt, ibid., Vol. XXIX, 1899, p. 24.

The origin of the corundum in these peridotite rocks is discussed on page 334, where it is stated that the large deposits of this mineral are found in places where there is a scarcity of chromite, and that little or no corundum has been found where the larger deposits of chromite occur.

Crystallized chromite has been found only in small, isolated crystals scattered through the peridotite, or in alluvial deposits where these crystals have been concentrated. The masses of chromite show little or no crystalline structure.

In a letter from the Maryland Geological Survey regarding the amount of chromite in the peridotite rocks of that section it was stated that: (1) "none of the serpentine or peridotite sections shows any noticeable amount of chromite;" (2) "analyses of the peridotite show 0.5 per cent of chromic oxide."

The constant occurrence of the chromite in rounded masses of varying proportions near the contact of the peridotite with the gneiss, and its occurrence in the fresh as well as the altered peridotite, indicate that the chromite has been held in solution in the molten mass of the peridotite when it was intruded into the country rock, and that it separated out among the first minerals as this mass began to cool.

As has been said on page 344, the peridotite magma, holding in solution the chemical elements of the different minerals, would be like a saturated liquid, and as it began to cool the minerals would separate or crystallize out, not according to their fusibility but according to their solubility in the molten magma. The more basic portions being the less soluble, would be the first to separate out, in conformity to the general law of cooling and crystallizing magmas. These would be the oxides containing no silica; in the present case the chromite, spinel, and corundum. These minerals would solidify or crystallize out where the molten magma first began to cool, which would be at the contact of the mass with the country rock; convection currents would tend to bring new supplies of material to the outer boundary, which would deposit its chromic oxide as chromite.

The more fluid a molten mass of rock becomes the more favorable will be the conditions for rapid and effectual connection, and it is in these very basic magnesian rocks that we find the best illustrations of the separation and concentration of the more basic minerals. The longer the chromite remained in solution, the less opportunity there would be for it to separate out in sharp, distinct masses, and as the molten magma began to lose some of its fluidity, it would tend to separate out in smaller bunches, or in grains scattered through the peridotite. Where the percentage of chromic oxide in the magma was very small, it would have a tendency to separate out more evenly throughout the mass; and where chromite and corundum are found in the same mass of peridotite, the corundum is very close to the contact and between it and the chromite, which grades out into the peridotite.

In some cases a portion of the magma seems to have been chilled against the enclosing walls before any considerable part of it had been cooled to the saturation point for the dissolved chromite. Thus, between the chromite and the gneissic rock there is often a seam of the peridotite.

This would account for all the irregularities of the chromite deposits—their pockety nature, and the apparent non-relation or non-connection of one pocket of chromite with another, the shooting off of stringers from the main masses of the chromite into the peridotite, the widening and pinching of the chromite " lodes," the intimate mixture of peridotite and chromite, and the gradation from the nearly pure masses of chromite through a mixture of chromite and peridotite to the pure peridotite.

The work done in the North Carolina chrome mines has not been sufficient to demonstrate the position and relation of the chromite deposits to the gneiss or other country rock, as clearly as it has been demonstrated in the Canadian deposits. According to the above theory the chromite would be concentrated near the borders of the peridotite in rounded masses. The pockets of chromite found in the midst of a peridotite formation, which at the present time are isolated and have no connection with one another, are conceived to have been, at the time of their formation, part of the chromite concentrated near the border of the peridotite in rounded masses; but the extensive erosion to which these rocks have been subjected has worn them down to their present condition, as represented in fig. 35, which is an ideal cross section of the occurrence of chromite in peridotite soon after its intrusion into the gneiss. In fig. 35 the chromite area has of necessity been largely exaggerated. On comparing this figure with fig. 34, which represents a corresponding occurrence of corundum, it will be noted that the corundum areas are represented as more compact and regular and that they are directly at the contact of the gneiss. The separation of the corundum from the basic magma at an earlier stage than the chromite will explain this, and thus the chromite is represented with a narrow seam of peridotite between it and the gneiss, which is nearly always present; with particles of peridotite in the masses of chromite; and with a mixture of chromite and peridotite merging into the pure peridotite. This is well illustrated by the occurrences at Black Lake, Canada, especially in the openings near Caribou Lake.

In prospecting for either chromite or corundum the largest and richest deposits may be expected near the contact of the peridotite with the gneiss or other country rock. This is the experience of miners and prospectors, and is entirely in accord with the theory here adopted.

Chromite has been found only in peridotite and serpentine, and the presence of this mineral in a rock may be accepted as strong evidence of igneous origin. It is conceivable that some peridotites may be of metamorphic origin; that they might have been formed by the metamorphism of dolomitic limestones containing iron in the form of $FeCO_3$ as in $(MgFe)CO_3$, or beds of siderite rich in magnesia, silica in the form of sand being probably present. Rocks of this type, when subjected to great heat in the presence of moisture, would have their carbonic acid almost completely driven off, and silicates would be formed, perhaps, according to the formula $2MgCO_3 + SiO_2 = Mg_2SiO_4 + 2CO_2$.

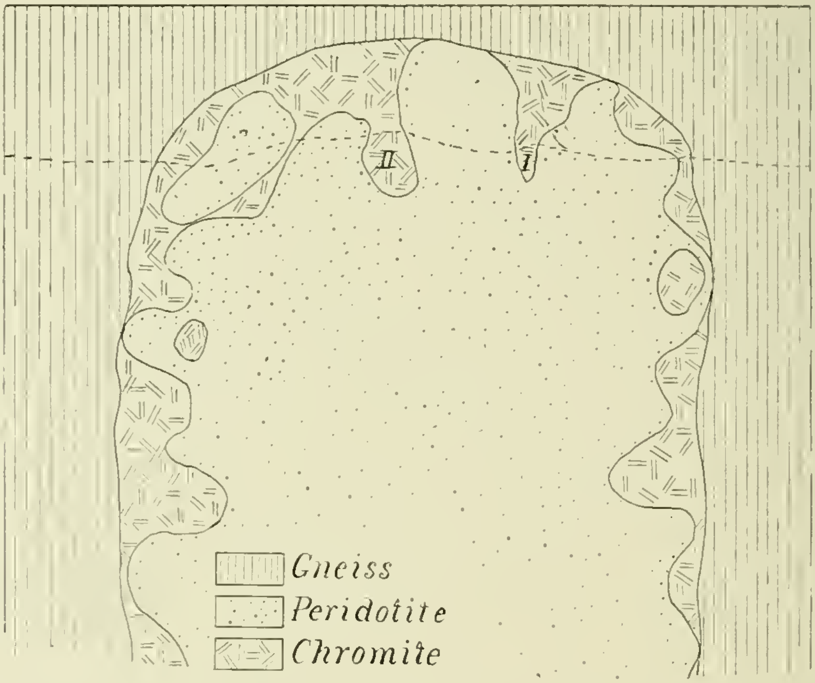

FIG. 35.—Ideal vertical cross section of a chromite-bearing mass of peridotite after its intrusion into gneiss.

If a peridotite were formed in this manner we should expect to find some carbonates associated with it, we should not expect to find any chromite or spinel, and the resultant product would not appear in the forms characteristic of intrusive dikes, sheets, and laccoliths. On the other hand, the presence of chromite or spinel and the absence of carbonates and many other characters, strongly indicate that the peridotite is of igneous origin (see Chapter III).

The large deposits of chromite in the serpentine rocks of Pennsylvania and Maryland in the United States, and of the Province of Quebec in Canada, are associated with igneous rocks of exactly the same nature as the peridotites of North Carolina, and have doubtless solidified out from the molten magma, as described above.

A natural corollary to be drawn from this proposition is that the occurrence of chromite in an alluvial deposit indicates the proximity of a peridotite of igneous origin, which was the original source of the chromite.

The association of platinum with chromite and serpentine in various parts of the world where platinum has been found in alluvial deposits indicates that the platinum originated from a peridotite or allied rock of igneous origin. On the eastern slope of the Urals platinum has been found associated with chromite, which is disseminated through an olivine rock. It is not unreasonable to expect that platinum will be found in some of the peridotite areas of the United States.

CHEMICAL COMPOSITION OF CHROMITE.[2]

REVIEW OF ANALYSES.

In order to determine the chemical composition of chromite all the available analyses were examined and analyses were made of chromite from Price Creek, 6 miles southwest of Burnsville, Yancey County; Webster, Jackson County; and Corundum Hill, Macon County, N. C. Pure material for analysis showing no impurities when examined under the microscope, was readily obtained by hand picking. Analyses I and II below, were made by Dr. Charles Baskerville, of the University of North Carolina, and III by Dr. H. W. Foote, of the Sheffield Scientific School, Yale University.

Analyses of chromite from North Carolina.

	I.		II.		III.	
Constituent.	Price Creek.	Ratio.	Corundum Hill.	Ratio.	Webster.[3]	Ratio.
Cr_2O_3	59.20	0.386	57.20	0.377	39.95	0.261
Al_2O_3	7.15	.070	7.82	.076	29.28	.287
FeO	25.02	.347	25.68	.356	13.90	.193
MgO	4.42	.111	5.22	.131	17.31	.433
SiO_2	3.20	...	2.80	...	...	...
MnO	.92	...	.69	...	...	...
Total	99.91	...	99.41	...	100.44	...

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[2] Pratt, Am. Inst. Min. Eng., Vol. XXIX. 1899, p. 30; Am. Jour. Sci., Vol. VII, 1899, p. 281; and U. S. Geol. Survey, Min. Res., 1900, pamphlet.

[3] This analysis is of the mitchellite variety of chromite, and does not represent the ordinary chromite that occurs in this vicinity.

In the above analyses the ratio of the bivalent oxides to the trivalent oxides is uniformly high and can probably be accounted for by the fact that some of the iron calculated as FeO was in the ferric state, as was proved in the Webster chromite.

Taking enough of the Cr_2O_3 and MgO to unite with the FeO and Al_2O_3, respectively, to form the molecules $FeCr_2O_4$ ($FeO.Cr_2O_3$) and $MgAl_2O_4$ ($MgO.Al_2O_3$), there remains approximately enough of the Cr_2O_3 to unite with the excess of MgO. The nearer the ratio of the bivalent oxides approximates that of the trivalent the nearer the excess of the Cr_2O_3 and MgO equalize each other. Inability to determine the ratio of ferrous to ferric oxide in the above analyses prevents the obtaining of a sharp ratio in the excess of the Cr_2O_3 and MgO.

In all the terrestrial chromite analyses examined, with the exception of two, alumina and magnesia are present, varying from a small percentage in some analyses to more than 20 per cent in others. The alumina usually varies with the magnesia, specimens rich in magnesia being correspondingly rich in alumina.

This constant occurrence of magnesia and alumina in the chromites would seem to indicate that the molecule of the mineral we now call chromite is not pure $FeCr_2O_4$, but a combination of the three isomorphous molecules, $FeCr_2O_4$; $MgCr_2O_4$; and $MgAl_2O_4$.

Only two analyses of specimens of chromite (terrestrial) have been found that do not show the presence of magnesia and alumina. The first was a magnetic chrome-sand from Chester, Pa., analyzed by Mr. T. H. Garrett,[4] in which all the iron is calculated as ferric oxide; the second was chromite from Vache Island, West Indies, analyzed by Mr. J. Clouet.[5]

Analyses of chromite from Chester, Pa., and Vache Island, West Indies.

Constituent.	I. (Garrett).	II. (Clouet).
Cr_2O_3	41.55	51.53
FeO	....	48.46
Fe_2O_3	62.02	....
SiO_2	1.25	....
Total	104.82	99.99

A greater part of the iron in Mr. Garrett's analysis is undoubtedly in the form of ferrous oxide, as is indicated by the high total percentage

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[4] Am. Jour. Sci., 2d ser., Vol. XIV, 1852, p. 47.

[5] Ann. Chem. et Phys., 4th ser., Vol. XVI, 1869, pp. 90-100; and Lithological Studies, by M. E. Wadsworth, p. iv of Appendix.

(104.82) obtained. Mr. Garrett also analyzed a massive chromite from near Chester, Pa., which showed only the presence of $Cr_2O_3 . FeO$ and a little NiO. From the above it is seen that a pure chromite, having the composition of $FeCr_2O_4$ ($FeO . Cr_2O_3$), is not common in nature.

Magnesium aluminate ($MgAl_2O_4$), occurs nearly pure in nature as normal spinel. The normal magnesium chromate ($MgCr_2O_4$), has not been found in nature; but as is indicated by the above analyses, there is good reason to believe that this does exist, and we may expect to find it occurring in nature as a definite mineral.

Under this theory of the composition of the chromites, the formulæ of the three analyzed would be as follows:

1. Price Creek, $10FeCr_2O_4$; $MgCr_2O_4$; $2MgAl_2O_4$.
2. Corundum Hill, $9FeCr_2O_4$; $MgCr_2O_4$; $2MgAl_2O_4$.
3. Webster, $FeCr_2O_4$; $MgCr_2O_4$; $2MgAl_2O_4$.

The first two formulæ will represent approximately those of the majority of the chromites that have been found and approach the normal chromite, $FeCr_2O_4$ ($FeO.Cr_2O_3$), as their limit.

As the $FeCr_2O_4$ molecule decreases and the $MgAl_2O_4$ increases, the mineral would approach normal spinel, $MgAl_2O_4$ ($MgO . Al_2O_3$), as its limit, the mineral picotite or chrome-spinel being representative of a mineral near the spinel end.

Dr. Wadsworth,[6] in comparing the chromite and picotite associated with peridotite says:

> It is probable that picotite and chromite belong to the same mineral series, the term picotite being more commonly applied to the freshest states, and that of chromite to those forms more altered, and to the local aggregations arising from the migration of the chromic oxide during the alteration of the peridotite rocks. As a further extreme in the alteration a change to a more or less pure magnetite occurs.

Dr. Wadsworth's conclusions are deduced from a microscopic study of the minerals. As chromite is a mineral that suffers but slight alteration, most occurrences doubtless represent the original mineral and not an altered form. A beginning of alteration, however, has been observed in the Buck Creek chromite (p. 75) in which translucent grains are surrounded by an opaque mantle through loss of alumina and chromium oxide in the formation of the chlorite, kämmererite. With a decrease in the ratio of the molecule $MgAl_2O_4$, and a corresponding increase in the molecule $FeCr_2O_4$, the more opaque the mineral becomes.

These two minerals, picotite and chromite, belong to the same group and are closely allied to each other; but they represent two primary minerals, and not different stages in the alteration of one mineral.

[6] Lithological Studies, p. 184.

All the analyses of the mineral classified as picotite that have been examined show a nearly uniform composition, and one that is decidedly different from that shown by analyses of chromite.

In the analyses of the Webster chromite, mitchellite, the largest percentage of MgO was obtained, and in the calculation of the ratios the formula was shown to be $FeCr_2O_4$; $MgCr_2O_4$; $2MgAl_2O_4$; this being the highest ratio of the molecule $MgCr_2O_4$ in any chromite examined.

This analysis is similar to that described by Bock for the magnochromite from Grochan, Silesia, which contained Cr_2O_3, 40.78 per cent; Al_2O_3, 29.92; FeO, 15.30; and MgO, 14.

It is in order to designate this Webster chromite and others of similar composition that the name *mitchellite* was proposed.

METHOD OF ANALYSIS OF CHROMITE.

Chemists who first attempted to analyze chromite found a great deal of difficulty in bringing the mineral into solution, and the same difficulty has been experienced more or less to the present time. As chromite is the source of supply of chromium, and as its value depends upon its percentage of chromic oxide, it has to be constantly assayed. The method employed in making the analyses of chromite given on page 373 is as follows:

Ordinary method.—The ore is first ground to an impalpable powder under water in an agate mortar. The powder is fused several times with bisulphate of potash, then taken up with hydrochloric acid. If a residue is left this should be dried and fused again with bisulphate of potash. The solution is tested for silica, and then the iron, aluminum, and chromium are precipitated with ammonia, the precipitation being made at least three times in order to throw down all these metals free from magnesia. The precipitate of these mixed oxides is dissolved in hydrochloric or nitric acid and the excess of the acid evaporated. Sodium hydroxide is then added in excess and chlorine passed into the hot solution. The solution is then acidified and the iron and aluminum precipitated twice with ammonia, leaving all but a trace of chromium in solution. These oxides, after having been dried and weighed (if iron and aluminum are to be determined), are fused with acid potassium sulphate, digested with water, acidified, and one precipitation made with ammonia to partially remove sulphates. On filtering, this precipitate is redissolved by hydrochloric acid and treated as before, the trace of chromium remaining in the solution. This solution is then added to that obtained before, and to the combined filtrates, containing chromium, alcohol and hydrochloric acid are added and the solution is digested for some time. The chromium is precipitated by the addition of ammonia as hydroxide and weighed as Cr_2O_3. To insure the purity of the precipitate, fuse with four parts of sodium carbonate to one part of potassium nitrate, take up the fusion with water, and test for magnesium.

This method gives very satisfactory and accurate results, but one is required in the assay of ores that will give quick determinations of chromic oxide. The volumetric method described by Mr. A. G. McKenna will be found to be more rapid and at the same time sufficiently accurate.

McKenna method.—One half gram of the fine, ground sample which has been dried at 100° C. for one hour is weighed into a nickel crucible of about 20 cc. capacity, in which has been placed three or four grams of sodium peroxide; after thoroughly mixing the contents, the crucible is held over a Bunsen burner by means of a pair of suitable shaped tongs until fusion begins. The mass is kept in a liquid condition at a low red heat for about one minute, which is sufficient to ensure complete decomposition, if the ore is at all finely ground. After allowing the crucible to cool, it is placed in a 400 cc. beaker with a watch glass cover and hot water is added until the crucible is covered.

The beaker is placed on a hot plate for a few minutes until the fusion is dissolved; the crucible is then removed by means of a glass rod and the contents of the beaker are allowed to settle for a few minutes. When the insoluble matter has subsided it is collected on a 9 cm. filter paper, the filtrate being received in a 500 cc. flask. The residue on the paper, which contains all the iron, is ignited in a platinum crucible, fused with two or three grams of potassium bisulphate, dissolved in dilute sulphuric acid (1:10), reduced by filtration through amalgamated zinc, and titrated in the usual manner with standard permanganate. The result is calculated to ferrous oxide.

The filtrate in the 500 cc. flask, which contains all the chromium as sodium-chromate in an alkaline solution, is boiled for about ten minutes in order to insure the removal of all peroxide which, if allowed to remain until the solution is acidified, would react on the chromate, reducing it to the sesquioxide.

When the removal of the peroxide is complete, the solution is allowed to cool and then acidified with a large excess of dilute sulphuric acid (1:4).

The solution is transferred to a 1,000 cc. beaker, and diluted to about 800 cc. with cold water. To this solution 70 cc. of a ferrous sulphate solution, containing 10 grams of Fe in the ferrous condition to the liter, is added. This is sufficient to reduce the chromic acid corresponding to .3167 grams of chromic sesquioxide. The excess of ferrous sulphate which has been added is determined by back titration with standard permanganated solution, of which 1 cc. is equivalent to 1 cc. of the ferrous sulphate solution. Such a permanganate contains 5.643 grams $KMnO_4$ to the liter. The difference between the cubic centimeters of ferrous sulphate used and cubic centimeters of permanganate used, multiplied by .905, gives percentage of chromic sesquioxide in the ore.

There is one suggestion regarding this method that may be of some advantage and that is the use of a mixture of sodium hydroxide and sodium peroxide in the fusion of the chrome ore, instead of the peroxide alone. The hydroxide would tend to decrease the violence of the reaction and thus there would be less chance of loss by spattering.

Tests for chromium.—In testing for chromium the colors which it imparts to the fluxes are usually sufficient to serve for its detection as follows:[7]

1. When a very little of the oxide of chromium is dissolved in a borax bead before the blow pipe the bead will be decidedly yellow when hot, changing to yellowish green when cold. With the addition of more of the chromium oxide the bead is red when hot, changing to a fine yellowish green when cold. In the reducing flame the bead assumes a fine green color and shows none of the yellow color which was so prominent after heating in the oxidizing flame.

2. With a salt of phosphorus bead the colors in the oxidizing flame are a dirty green when hot, changing to fine green when cold, and are about the same but not so decided in the reducing flame.

CHROMITE LOCALITIES.[8]

LOCALITIES IN THE UNITED STATES.

The mining of chromite in this country has always been attended with considerable uncertainty on account of the pockety nature of the deposits, for, as has been stated, chromite is not found in veins, but in pockets or bunches of ore of varying dimensions, which may or may not be connected with one another and are limited in extent; so that with the exhaustion of a particular pocket of chromite, there will often be more or less dead work to be done before another is encountered. Usually no estimate can be made regarding the amount of chromite on a property beyond that which is exposed by the actual work done. The fact that 10 tons or 10,000 tons have been taken out of one pocket does not signify that it is still a good deposit, but if a certain pocket has been productive of a large yield, this would serve as a strong indication of the existence of other pockets near by. Yet, in view of the theory advanced for the origin of chromite, if a deposit of this mineral is found near the contact of peridotite and other country rock, and if this peridotite formation is very extensive and the chromite is found in considerable quantity, there is a probability that large deposits will be found in the area.

The first supply of chromite in this country was obtained from

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[7] See Penfield's Determinative Mineralogy, 1898, p. 69.

[8] Min. Res., U. S. Geol. Survey, 1900, Pamphlet on Chrome Ore.

Chester and Delaware counties, Pa., and Baltimore County, Md. As these deposits began to be exhausted, chromite was discovered in California, and for a time the deposits in the neighborhood of San Luis Obispo furnished practically all the chrome ore used in the United States. This ore was soon superseded by chromite imported from Turkey and Russia, with smaller amounts from Quebec and Newfoundland.

Pennsylvania and Maryland.[9]—These two States were formerly the source of the chromite supply for the United States. The deposits were located in Chester and Delaware counties, Pa., and in Baltimore, Cecil, and Harford counties, Md. The most celebrated of the mines in Pennsylvania was the Wood chrome mine, situated not far from Horsefoot Ford of the Octoraro River. To the south of the Wood is the Line mine, so named because it was situated immediately on the boundary line between Pennsylvania and Maryland.

The more important deposits at which chromite was mined in Maryland were in Green Spring Valley, at Bare Hills, Soldiers Delight, and Owings Mills, in Baltimore County. These mines, however, are supposed to be practically exhausted, and but very little chromite is now obtained from this State. About 2 miles northwest of Sylmar Station, on the Philadelphia, Wilmington and Baltimore Railroad, a small amount of chromite in the form of chrome sand is obtained from the Tweed chrome mine[10] on the property of Mansell Tweed. The property is about 3 miles southeast of the Wood mine referred to above.

The first chromite that was found in Maryland was on the Reed farm, located in Harford County, about 27 miles northeast of Baltimore. The attention of Mr. Isaac Tyson, Jr., was called to this chromite by noticing some heavy black stones that were used for keeping a barrel from rolling in a cart that stood in the city market place. On perceiving what they were and on finding where they came from, he immediately took means to obtain possession of the property on which they had been picked up, and this was the beginning of the chrome industry of the Tysons. The ore first mined was hauled to Baltimore and then shipped to Liverpool. The next discovery of chromite was in the form of sand in the beds of brooks on a tract of land called Soldiers Delight, in Green Spring Valley, Baltimore County, 16 miles northwest of Baltimore.

The following year, 1828, Mr. Tyson, while in Lancaster County, Pa., observed chromite on the Wood farm in quantity that far exceeded that which he had seen on the surface at the Reed mine. He at first leased the mineral right of the farm and finally acquired it in fee simple. This is the deposit that developed into the famous Wood mine, referred to above, which has furnished about 95,000 tons of chromite.

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[9] 2d Geol. Survey Pennsylvania, Vols. CCC, 1880, and C 4, 1883; Am. Inst. Min. Eng. Vol. XXV, 1895, p. 381; Min. Res. U. S., 1883-84, p. 568; Min. Res. U. S., Part III, 1895-96; and Geol. Surv., Md., Vol. I, 1897.

[10] Eng. and Min. Jour., Aug. 5, 1899.

The chromite mines near Rock Springs, in Cecil County, were the next ones discovered. These lie close to the Pennsylvania line, and as mining was continued the deposits were found to extend over the State line into Pennsylvania, and it is this deposit that is known as the Line mine.

Most of the chromite ore that has been obtained from Maryland has been in the form of sand. South of Baltimore diligent search has been made for chromite, but no indications of profitable deposits have been observed. The valuable chromite territory that is known to exist in Pennsylvania or Maryland lies in a strip of land extending from Soldiers Delight, 16 miles northwest of Baltimore, to the Boone farm, 10 miles east of the Wood mine, making a total distance of about 60 miles. There are still valuable chromite sand deposits in this section, but they cannot compete with that imported from Turkey.

California.[11]—Along the Pacific coast basic magnesium rocks are found abundantly, especially in California, where they are known to outcrop in at least thirty counties. Associated with many of these rocks is chromite, and at a number of localities it has been mined. The following counties are those in which chromite deposits of some extent have been located: Alameda, Calaveras, Del Norte, Fresno, Mendocino, Napa, Placer, San Luis Obispo, Santa Clara, Shasta, Sierra, Sonoma, and Tehama. Besides these counties, there are many others in which chromite has been observed, although nothing has been done to determine whether or not it occurs in quantity.

More or less platinum has been found in the placer deposits of many of the counties, although none has been found in place in this State. Where platinum has been found in place it is with peridotite rocks and with chromite. The extensive outcrops of these peridotite rocks or their alteration product, serpentine, that occur in California, associated with which there is more or less chromite, seem to offer a very promising field for platinum prospecting as well as chromite. It is not unreasonable to expect that platinum will be found in quantity in places in this rock.

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[11] Min. Res. U. S., 1882, p. 428; 1883-84, p. 569; 1885, p. 355; 1886, p. 176; 1887, p. 132; 1890, p. 119; California Mines & Minerals, by Cal. Miners' Assoc., San Francisco, Cal., 1899, pp. 49, 331, 389; Geol. Surv., Cal., Vol. 1, 1865, pp. 19, 59; and Ann. Rept. State Mineralogist, 1884, p. 126, and 1886, p. 100.

North Carolina.[12]—Although prospecting for chrome ore in this State was first undertaken over thirty years ago and has been continued spasmodically ever since, there has never been any systematic development of the localities.

In the alluvial deposits at the base of the peridotite outcrops there is usually a considerable amount of chromite crystals and particles, but nowhere have they been observed in sufficient quantity to constitute a chrome sand ore.

The chrome ore is nearly uniform in general character throughout the entire area, being very hard and compact, though often of a fine granular appearance, and there is but litle that is at all friable. The masses of chromite are usually very free from seams of peridotite or its alteration products. This simplifies the concentration, and a high grade ore can usually be obtained by cobbing and hand picking.

In the following descriptions of localities only those are mentioned in which the chromite occurs otherwise than in grains or small nodules, and full description is given only of those localities in which the ore is found in quantity.

Mr. H. B. C. Nitze[13] mentions the occurrence of chromite in small pockets or seams in the drainage basin of Cove Creek, Watauga County, 7 miles northwest of Boone. On the farm of David Lawrence a pocket of chromite was opened that yielded about 10 tons of ore. When this pocket had been exhausted no further prospecting was undertaken.

In Yancey County, one of the two most important deposits in the State occurs at Mine Hill, on the Mine Fork of Jack Creek, 5 miles north of Burnsville, the county seat, on the Bakersville Road, where a large peridotite (dunite) formation outcrops on both sides of the road. Seams or pockets of chromite ore are abundant in this peridotite, varying from 0.5 inch to 3 inches in thickness. Near the summit of the hill, on the east side of the road, about 150 feet above the road and stream bed, a deposit of chromite has been opened from which 25 tons of ore were taken, a large part of which still remains on the dumps. A pit 9 feet deep was sunk on the deposit; but this has been filled with water since the work ceased, so that no estimate can be made of the extent of the deposit. Mr. Garrett Ray of Burnsville, N. C., the owner, reports that the chromite widened to between 2 and 3 feet at the bottom of the pit. There are other promising seams or veins which appear to indicate the existence of a deposit of chromite ore near the contact of the peridotite and gneiss.

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[12] Am. Inst. Min. Eng., Vol. XXIX, 1899, p. 36; Eng. and Min. Jour., Aug. 18, 1900; Seventeenth Ann. Rept. U. S. Geol. Survey, Part. III, 1896, p. 461; Min. Res. U. S., U. S. Geol. Survey, 1900, Pamphlet on Chrome Ore.

[13] Bull. North Carolina Geol. Survey No. 1, p. 212.

On the west side of the road the peridotite formation rises in another hill, and here there are numerous small seams and pockets of chromite. On the extreme western slope of the formation a trench has been cut 100 feet or more into the hill, in which are exposed many small pockets of chromite. The work done in this trench is of a prehistoric character, and whether the object of the exploration was chromite or not has never been explained.

With the exception of the pit sunk near the summit of Mine Hill, from which a few tons of ore were shipped, no mining has been done here, and very little prospecting has been undertaken to determine the exact extent of the chromite deposits. The distance from the railroad has greatly discouraged systematic prospecting in this region. The shipping point at the time this work was done was Asheville, on the Southern Railway, about 40 miles to the south. The railroad from Erwin, Tenn., to Marion, N. C., which is now partially completed, passes within 3 or 4 miles of this locality.

An analysis of a selected specimen of the chromite (Baskerville, analyst) gave the following results:

Analysis of selected specimen of chromite from Mine Hill, 5 miles north of Burnsville, Yancey County.

	Per cent.		Per cent.
Cr_2O_3	58.00	MgO	8.26
Al_2O_3	15.52	SiO_2	3.20
FeO	14.45	CaO	.70

Although this analysis represents a selected sample of the chromite, yet from the character of the material it is not unreasonable to expect an ore that, by handpicking and cobbing, will assay in the neighborhood of 52 per cent of chromic oxide, with a low percentage of silica.

About 9 miles west of Burnsville, near Price Creek, there is a narrow bed of peridotite on the land of Mr. W. A. Robertson, a quarter of a mile from Price Creek post-office. A pocket of chromite discovered here yielded nearly 7 tons of ore. This exhausted the pocket and since then no prospecting has been done in this vicinity.

An analysis of a selected sample of this ore (Baskerville, analyst) gave the following result:

Analysis of selected sample of chromite from Price Creek, 9 miles west of Burnsville, Yancey County.

	Per cent.		Per cent.
Cr_2O_3	59.20	MgO	4.42
Al_2O_3	7.15	SiO_2	3.20
FeO	25.02	MnO	.92

In Jackson County, in the vicinity of Webster, there is a large peridotite (dunite) formation extending from about half a mile north of the town to a mile and a quarter south. The widest part of the area, about half a mile, is at Webster, the town being partly built on the dunite hill. The Tuckaseegee River cuts through this formation about half a mile below the town. Considerable prospecting has been carried on in this region, and numerous veins and pockets of chromite of varying extent have been discovered.

The only deposit of any note found on the north or Webster side of the river is on the east side of the Tuckaseegee road, about 200 yards from the main street of the town, on the land of Daniel Schneider. A pocket of chromite was uncovered here which yielded a number of tons of chromite, most of which was shipped. At a depth of nearly 9 feet the pocket pinched out, leaving but a small seam of chromite in sight. Many small seams and pockets of chromite are to be seen, but no other work has been undertaken for chromite on this side of the river.

On the south side of the river, following closely the contact of the dunite with the gneiss, a line of prospect pits has been dug which shows the presence of a considerable amount of chromite. The prospecting has been done on the lands of Joseph Hooker, Lawrence Buress, Alf Wilson, James Ashe, and Daniel Fullbright, all of Webster, N. C. The most promising deposits are one on the land of James Ashe, where a cut 25 feet long, 6 to 8 feet wide, and 8 to 10 feet deep was sunk on a vein of chromite 12 to 18 inches thick, which at the bottom of the cut is 12 inches thick; and another on the land of Daniel Fullbright, where a seam nearly 12 inches thick is exposed in the branch. The nearest shipping point is Sylva, on the Southern Railway, 3 miles north of Webster.

Chromite has been found at a number of places in the masses of peridotite within 2 or 3 miles southwest from Balsam Gap, Jackson County. The most promising outlook for a large deposit is on Dark Ridge Creek, about 525 feet south of the Dark Ridge trestle of the Murphy Branch of the Southern Railway. On the east side of the creek a cut 18 feet deep and 10 feet wide was made on the pocket of chromite, from the bottom of which two seams of chromite, 6 and 8 inches thick, respectively, extended. Fifteen tons of ore were taken out of the main pocket. About 200 yards farther south, on the opposite side of the creek, a shallow pit was sunk which encountered considerable chromite. Both these openings were near the contact of the peridotite and gneiss. Between these and in their near vicinity there is a large quantity of float ore. These facts point to this locality as one worthy of further development, with an expectation of finding a large quantity of ore. Its proximity to the railroad is also a great advantage. Analyses show the ore to carry about 49 per cent of Cr_2O_3. The property is owned by the Highland Forest Company, of Waynesville, N. C.

No large deposits of chromite have yet been found in North Carolina, but the work done shows that extensive deposits may exist in the State, those described above being the most promising ones known.

The standard chrome ore contains 50 per cent of Cr_2O_3, and the value of the ore increases with each unit over this. Ores as low as 45 per cent of Cr_2O_3 find a ready market if they are low in silica. The North Carolina ores are of high grade and are usually low in silica.

FOREIGN LOCALITIES.

Turkey.—Most of the chromite that is brought into the United States comes from Turkey.[14] There are two principal regions in which the chrome deposits are located; the European field, of which the province of Uskup, on the river Vardar, is the principal province, and whose shipping point is Salonica; and the Asiatic field, of which the government of Broussa and the government of Smyrna are the two principal districts. These ores usually carry from 50 to 52 per cent of chromic oxide, and the mines are probably the most extensive now in operation.

Turkey furnishes most of the chromite supply for the world, and it has been estimated that there is enough chromite in sight at a number of different places in Turkey to more than supply the world's demand for many years to come. If, however, chromite could be found in sufficient quantity with a high enough per cent of chromic oxide it could enter into competition with the Turkish chromite if transportation facilities were given.

Russia.—Only scattered references can be obtained regarding the chromite deposits of Russia,[15] which are associated with the basic magnesian rocks of the Urals. The mineral is found in large granular masses in these rocks in several places near Ekaterinburg, also 8 miles from Bessirk, and near Kyschtinsk. Chromite is also found at the platinum placer mines at Nizhne-Taghilck, in the Goroblagodat region.

Chromite has also been mined in Greece.

New Caledonia.—The deposits in New Caledonia are beginning to be worked to considerable extent. The ore is, as a rule, shipped from Numea to Australian ports, and thence to Europe as ballast in ships laden with wool; from there some of it is reshipped to this country.

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[14] Nineteenth Ann. Rept. U. S. Geol. Survey, Part VI, 1898, p. 261.

[15] Min. Res. U. S., 1890, p. 120.

It is very probable, however, that steamers will load at Numea and come directly to this country.

Deposits of chromite have also been found in New South Wales.

Cuba.—Serpentine rocks are found rather abundantly in portions of Cuba, especially in Puerto Principe province, but they have been studied only a little, so that information regarding them and their exact locality and occurrences is meager. Chromite has also been found in this province, but the exact locality could not be ascertained. The specimen seen weighed about a quarter of a pound and was hard, tough, massive chromite, which did not show any seams of impurities. It is not at all improbable that, as investigations are carried on regarding the geology and mineral resources of Cuba, this serpentine or other basic magnesian rocks will be found to contain chromite in quantity.

Newfoundland.—The deposits of this mineral in Newfoundland are attracting considerable attention, and many tons of the ore have been imported into the United States, although the per cent of chromic oxide is only about 49. The deposits are located at Bluff Head, on Port au Port Bay, on the west coast of Newfoundland,[16] about 30 miles from Sandy Point, on Bay St. George. This point can be reached by steamer from Halifax and North Sidney, Cape Breton.

Bluff Head is a bold headland which rises almost vertically from the shore, between which and another headland of less altitude, about a mile and a half to the north, the shore line drops down to about a hundred feet, the high hills receding for 1½ to 2 miles. As far as has been determined, the country rock of this section is principally a diorite, which is traversed by numerous broad belts of serpentine of a dark-green, almost black, color. Large bodies of chromite were found in this serpentine, and the mining of this mineral has developed into an industry of some importance for Newfoundland.

The ore varies considerably in its percentage of chromic oxide, some samples showing as low as 39 per cent, and others as high as 50 per cent, with the larger amount of the ore ranging from 47 to 49 per cent. Mining has been continued here since the deposit was first discovered, and it still remains the most important chromite locality on the island. But little chromite has been mined during the past 2 years, mainly on account of the short season available for mining and shipping, but also because of the difficulty in shipping the ore, which has to be loaded on the steamers and sailing vessels by means of scows and dories.

Canada.—The Canadian chromite deposits are in the Province of

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[16] Am. Inst. Min. Eng., Vol. XXVII, 1897, p. 283.

Quebec, occurring in the belt of altered peridotite rocks (serpentine) that are found in the vicinity of Black Lake and Colraine. A granitic rock is the main country rock of this district. The peridotite rocks in this general district form a series of approximately parallel belts of varying width, which can be traced in a general northeast-southwest direction for a distance of over 20 miles. These rocks are not continuous in this distance, but are interrupted by masses and narrow dikes of the granitic rock. Seams and smaller masses of granite are found entirely surrounded by the peridotite or its altered facies, serpentine.

From this section there has been in the neighborhood of 25,000 tons of chromite shipped, which was obtained from many openings, some of which have been worked to a depth of more than 100 feet. A considerable part of the ore mined consists of a more or less intimate mixture of chromite and serpentine, which has to be milled and concentrated before its percentage of chromic oxide is sufficiently high to make it marketable. The ore that is sold crude varies in its contents of chromic oxide (Cr_2O_3) from 45 to 51 per cent. The ores will not, as far as can be judged, make high grade ores, and while they will approximate 50 per cent, they will be more likely to be under this. Many of these deposits are favorably located for mining and all are within a few miles of the Quebec Central Railroad. These deposits are now being worked by three different companies, and the output is expected to be constantly increased for some time to come.

USES OF CHROMITE.[17]

The uses of the mineral chromite are somewhat varied, and can readily be brought under three heads:

1. Uses of the mineral itself.
2. Uses of chromium alloys and metallic chromium.
3. Uses of chromium salts.

It is only within the past two years that there has been any use for the metal itself in the arts. Metallic chromium has been prepared by intensely heating the oxide with charcoal, or by reducing, at high temperatures, the chromium chloride with zinc. The metal obtained in this way is as hard as corundum, and is more infusible than platinum. According to the Journal of the Franklin Institute of Philadelphia,[18] good deposits of chromium can be obtained on a carbon cathode, or on platinum, brass, or lead, by means of a divided cell containing a chromic salt at the cathode and an acid or saline solution at the anode. The electrolytic chromium obtained in this way is bright gray and lustrous, but it has a tendency to peel, due probably to films of an oxide.

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[17] Pratt, Min. Res. U. S., U. S. Geol. Survey, 1901, pp. 941-945; and 1903, p. 298.

[18] November, 1901; and Eng. and Min. Jour., November 16, 1901.

With the introduction of the Goldschmidt thermit process for the reduction of the metallic oxides to the metal by means of powdered metallic aluminum (see description, page 337), it has become possible to produce the metal chromium commercially.

1. *Chromite as a mineral* is used in the manufacture of bricks for basic open-hearth furnaces. One method of preparing these bricks is by the mixture of chrome ore, bauxite, and milk of lime. The Harbison and Walker Company, of Pittsburgh, Pa., has, during the last few years, made very extensive experiments regarding the manufacture of chrome bricks, and is producing a brick that is giving very good satisfaction. These bricks have been used as linings on a number of furnaces, and at one furnace over 400 heats were turned out before the lining had to be replaced. Although the price of these chrome bricks is considerably higher than that of silica bricks, yet on account of their lasting so much longer they are much more desirable. They are also found to be useful for quick repairs in a furnace while it is running at full heat, as the chrome bricks are not affected by either sudden heating or sudden cooling. Their use in the back walls of gas-ports has decreased, and a magnesia brick has, as a rule, been substituted for them. It can also be used to advantage for lining the top hole and lip of blast furnaces, as it is very little affected by either the molten metal or slag.

Another use that is being advocated for the mineral chromite is as a hearth lining for water-jacket furnaces in copper smelting, and this use has already begun to a limited extent. In general, it may be said, that wherever chromite has been thoroughly tried in this way it has given satisfaction. There are a number of reasons why chromite is well adapted for this purpose: It is infusible; it does not become friable when heated and cooled; it is not affected, practically, at all by sudden heating or cooling; it is attacked by the products formed in the fusion of the copper ore; and, on account of its hardness, it will be worn away but slowly by the flow of the fluids over it. At the Richmond meeting (1901) of the American Institute of Mining Engineers, Mr. William Glenn, of Baltimore, presented an interesting paper on The use of chromite as a hearth lining for a furnace smelting copper ore. This paper gives the results of the construction of a chrome-ore bottom for a water-jacketed cupola copper furnace built at the Elizabeth mine in Stratford, Vt. The work on this furnace was done under the management of Mr. James W. Tyson, Jr., of Baltimore. The method of construction of the bottom of the furnace, which was to contain the chrome ore, is described as follows:

> To contain the chrome ore and form with it the furnace bottom, he constructed a cast-iron basin with surrounding flange, the outer edges of which coincided with the exterior walls of the water jacket. The bottom of the basin is a united arch of 36-inch chord and 12-inch versed sine, and 1 inch in thickness, except the flanges, which are 1.5 inches thick. It is in two sections, each of which is 5 feet 7 inches long Each section is reinforced by three ribs, 1 inch in thickness and depth, by means of two of which the sections were bolted together with an asbestos gasket in the joint. The two outer ends of the basin were closed by segments which were cased with the sections. The basin was supported by ten jackscrews placed under its flanges, and was thus held securely up against the bottom of the water jackets, leaving free for inspection the entire underside of the basin. The chrome ore was filled into the basin, just filling the basin and reaching no higher than the bottoms of the four water jackets which form the four walls of the cupola. The ore used was of all sizes, from 10-inch cubes and downward through all dimensions even to dust.

Mr. Glenn states that no perishable cementing material was employed.

> The lumps of ore were fitted in as well as possible; the interstices were then filled in with smaller lumps, which were hammered in; finally, the cracks were filled with ground ore, thus making the bottom of the furnace consist of well-packed ore. A course of fire bricks, standing on end, was laid over the whole of the chrome-ore hearth. It has not been determined what depth of fire brick should be employed, or whether any covering at all is needed. This chromite cupola bottom has given good satisfaction for over a year, where a corresponding fire-brick bottom would not have lasted more than a week.
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> A blister-copper reverberatory furnace was erected at the same mine in Stratford, Vt., and chromite was used in the hearth and adjacent walls, the bridge wall being entirely constructed of chrome ore. The slag line of the hearth was built around with chrome ore, and neither this nor the bridge wall has shown any noticeable attack upon them.
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> Our experience leads us to believe that the bridge wall of a blister-furnace should be lined with blocks of chrome ore, compacted, as far as possible, and that the slag line of the furnace hearth should be formed of blocks of chrome ore about 10 inches in height. We would build the larger blocks into the walls, as best we could, and then wedge the smaller ones in among them. The work would appear rude and unskillful when looked upon after completion. Blocks of chrome ore are rough in outline; they do not readily lend themselves to wall building. There is no mortar wherewith to form an inviting exterior to the work, and there is no other deceitful adjunct present.

Chrome ore has been used to some extent, or is about to be tried, at the Ducktown furnaces at Ducktown, Tenn. The results that have been obtained from practical tests of the use of chromite in this capacity, and its known resistance to all kinds of acids and fused slags, which has been demonstrated in the laboratory, go to prove that as the mineral becomes better known among copper smelters it will be more universally used, and the smelters will find it true economy to make the linings of the furnaces of chrome ore. It is very probable that as more practical tests are made, chrome ore will prove equally available and useful in other furnaces and converters, and its use will permit of a more general use of the mineral fluorspar as a flux in smelting different ores. As far as can be determined, it is not necessary to use what are considered the best chromic iron ores, those that contain 50 per cent or more of chromic oxide; the lower grades of ore, carrying 40 per cent and upward of chromic oxide, are just as serviceable, and these ores are much more available and cheaper.

This use of chromite should produce a demand for the chromite ores of North Carolina, which would be available for the smelters at the Virgilina copper district of Virginia and North Carolina, the Ore Knob and Gold Hill copper districts of North Carolina, and the Ducktown district of Tennessee. In the same way the chromite deposits of California should become available for the same purpose in the copper districts of Arizona, Utah, and Montana.

2. *Chromium alloys.*—The principal use of chromium as an alloy is in the manufacture of ferro-alloy, and this has become a very important industry. The ferro-chromium alloy is used in the manufacture of chromium steel, which finds its greatest use in armor plate and armor-plate-piercing projectiles. The armor plates are usually made by the addition of the alloys, ferro-chromium and ferro-nickel, to the molten steel before it is cast into the ingot, and they produce a more or less homogeneous triple alloy. Chromium in the presence of carbon makes steel intensely hard. At the same time it gives it a high power of resistance to shock, which adapts it especially to use for armor plate, and also to any severe service, and to resistance to abrasion, as in trolley-car wheels, crusher jaws, stamp-mill shoes, etc. A chrome steel is now being made for use in the manufacture of safes.

In the manufacture of a ferro-chromium alloy it is necessary to use a high-grade chromium ore low in silica, which, on account of its refractory character, can be reduced only by the employment of electric heat.

Metallic chromium is now being used for the same purposes as the ferro-chromium alloy, as a steel hardening metal.

3. *Chromium salts.*—The chief use of chrome ores, notwithstanding the two uses described above, is still for the production of the salts, chromate and bichromate of potash, which are used particularly in dyeing

and in the manufacture of coloring material, or pigments. The availability of these salts as pigments was discovered about 1800, and, although at that time the discoverer thought that they might have valuable application in the arts, he was not able to determine this definitely on account of the rarity of the mineral crocoite, which was his source of chromium. With the discovery of chromic iron ore or chromite, however, it was soon demonstrated that these chromates of potash were very important pigments. They have become practically indispensable in the manufacture of textiles for many shades of buff, red, brown, and black. Artists require them for producing the purer tints of red and yellow, which are used in coloring and tinting pottery and various other kinds of objects. It has also been found that these alkali bichromates can be used advantageously in tanning skins. Some of the chromium salts are also used for medicinal purposes. Their greatest use, however, is still as pigments.

ASBESTOS.

There are mined and put on the market as asbestos two minerals that are very similar in their physical properties but are distinct chemically. One, a variety of the mineral amphibole, is a silicate of calcium and magnesium; the other is a variety of serpentine, a hydrous magnesium silicate, and is known as chrysotile. These two varieties of asbestos are equal in their heat-resisting properties, but the chrysotile is superior in strength and elasticity of fiber to any variety of amphibole asbestos. The former is usually greenish-white, green to yellowish in color, with a decidedly silky luster, while the other is from white to greenish and wood-brown in color and has more the appearance of flax. The fibers of the chrysotile asbestos vary from 1/16 to 3 inches in length, while fibers of amphibole asbestos have been found 3 feet in length. The two varieties can readily be distinguished from each other by testing them for water, the chrysotile being a hydrous mineral and giving off a considerable amount of water when heated. The modes of occurrence of these two varieties are distinct, the amphibole variety being usually in granitic or schistose rocks, sometimes in pockets and again in well defined veins, while the chrysotile variety is found in seams of varying thickness, always in serpentine rocks. For purposes where non-conductivity of heat is the important factor and not strength of fiber, the amphibole variety can be used and gives apparently as good results as the chrysotile. On the other hand, where strength of fiber as well as non-conductivity of heat is desired, the chrysotile variety is used, as in the manufacture of cloth, roping, felt, boards, tubes, and washers.

CHEMICAL AND MINERALOGICAL COMPOSITION OF ASBESTOS.

AMPHIBOLE ASBESTOS.

There are a number of minerals belonging to the amphibole group that occasionally assume a fibrous structure and are asbestiform in appearance. Where these occur in quantity they can undoubtedly be utilized as commercial asbestos, but they cannot be used for the same purposes as the chrysotile variety.

The amphibole that most commonly assumes a fibrous structure is tremolite. This crystallizes in the monoclinic system and its chemical composition is represented by the formula $(MgCa)\ SiO_3$, a magnesium, calcium meta-silicate. There are nearly always a little iron and alumina present, together with some moisture.

Anthophyllite, the orthorhombic amphibole, has been found with a fibrous structure at a number of localities and, as shown by Dr. George P. Merrill,[19] much of the asbestos that is called the amphibole variety (tremolite) is in reality anthophyllite. It is also true that many specimens that have at first been considered anthophyllite have proved upon close examination to be one of the monoclinic amphiboles and in some cases to be an enstatite. The chemical composition of anthophyllite is represented by the formula $(MgFe)SiO_3$, that is, it is magnesium iron meta-silicate. There are nearly always from a trace to several per cent of alumina and a small amount of moisture found in anthophyllite. Many mistakes of this character have been made in connection with the fibrous minerals occurring with the basic magnesian rocks that extend from Alabama northeastwardly to the Gaspé Peninsula in Canada. These, as a rule, occur in very small quantity. Occasionally a pyroxene is observed that has an asbestiform structure, this being more noticeable in the enstatite than in monoclinic pyproxene.

The following analyses[20] will illustrate the chemical composition of the tremolite and anthophyllite varieties of asbestos, and shows how readily anthophyllite, which contains but a very small amount of lime, can be distinguished from tremolite, which contains over 10 per cent.

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[19] Proc. U. S. Nat. Museum, Vol. XVIII, pp. 281-292.

[20] Proc. U. S. Nat. Museum, Vol. XVIII, p. 291.

Analyses of asbestos.

	I. Tremolite.	II. Tremolite.	III. Anthophyllite.	IV. Anthophyllite.
Silica, SiO_2	56.96	56.26	56.52	56.21
Alumina, Al_2O_3	.52	1.81	3.57	2.78
Ferrous Oxide, FeO	1.12	6.40	10.18	8.58
Lime, CaO	13.84	11.98	Trace.	.82
Magnesia, MgO	23.90	20.85	27.13	28.95
Manganese Oxide, MnO	....	Trace.	....	Trace.
Ignition, H_2O	2.37	2.65	2.96	2.23
Total	98.71	99.95	100.26	99.31

I. From Parkton, Md.; Geo. P. Merrill, analyst.
II. From Albemarle County, Va.; R. L. Packard, analyst.
III. From Rabun County, Ga.; Geo. P. Merrill, analyst.
IV. From Caldwell County, N. C.; Geo. P. Merrill, analyst.

As is well known, pyroxene suffers alteration very readily, passing over into some one of the amphiboles, and it is not improbable that considerable asbestos was originally a pyroxene. The fibrous structure of these minerals represents a crystalline phenomenon, and the individual fibers may be either distinct crystals more or less perfectly developed in the prismatic zone, or they may be due to abnormal cleavage that has been very highly and perfectly developed. There would be a tendency to distortion in the fibers, due to pressure and other forces to which the mineral may have been subjected. In some instances it is undoubtedly true that the fibrous structure has been produced by a process of shearing which has drawn out the mineral parallel to the vertical axis, and in recrystallization it has assumed the fibrous structure.

Dr. Geo. P. Merrill[21] sums up the results of his investigations as follows:

> The points brought out in this paper and the suggestions advanced are (1) that a very considerable proportion of the mineral in the commercial use, and labelled as asbestos in mineral cabinets, is in reality anthophyllite, and (2) that the fibrous structure in this case and that of the true asbestos as well, is due, in many instances at least, to a process of shearing—is, in fact, an exaggerated form of the process of uralitization.

That a great deal of the amphibole asbestos is the result of the alteration of a pyroxene is undoubtedly true, but it is also true that some of the asbestos represents an original amphibole mineral. It has not yet been definitely determined, however, whether or not this asbestos represents an original crystallization, although there is some evidence that the asbestos is not always a secondary mineral. Dr. Merrill believes "that the asbestos form is never a result of original crystallization, but is always secondary, the original mineral doubtless being an orthorhombic or monoclinic pyroxene, or perhaps an amphibole." As further stated by Dr. Merrill, there is an ample field for investigation along this line, in determining the original character of the different varieties of amphibole asbestos and also their present mineralogical character.

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[21] Ibid., p. 289.

CHRYSOTILE ASBESTOS.

This variety of asbestos is entirely distinct from the amphibole varieties. It is a fibrous serpentine, whose composition is represented by the formula $H_4Mg_3Si_2O_9$, a hydrous magnesium silicate. Chemically, it is readily distinguished from the amphibole varieties by its large content of water. Physically, it is more silky in luster and its fibers are stronger and more elastic. In the table below are given analyses of chrysotile, anthophyllite, and tremolite asbestos.

Analyses of asbestos.

Constituent.	I. Chrysotile Canada.	II. Anthophyllite Virginia.	III. Tremolite Georgia.
SiO_2	40.57	56.52	55.81
Al_2O_3	....	3.57	1.66
Fe_2O_3	.90	....	....
FeO	2.81	10.08	6.81
CaO	....	Trace.	12.74
MgO	41.50	27.13	21.09
H_2O	13.55	....	....
Ignition	....	2.96	1.81
Total	99.33	100.26	99.92

1. J. T. Donald, analyst.
2. R. L. Packard, analyst.
3. Geo. P. Merrill, analyst.

The fibers of this asbestos are usually perpendicular or at high angles to the walls, but very rarely they have been observed where they are parallel to them. They occur in serpentine, near the source of some local disturbances, as where granitic dikes appear in the serpentine or near the contact of the serpentine with the main mass of the country rock.

At many of the peridotite localities this fibrous variety of serpentine, chrysotile, has been found. Sometimes it occurs but very sparingly and even where the peridotite rocks are entirely altered to serpentine there is often little or none of the chrysotile variety developed. It has been observed sparingly in small seams in a number of the peridotite rocks that showed but slight alteration to serpentine. Not all of the peridotite formations that have been thoroughly converted into serpentine contain the chrysotile, and but few contain a sufficient amount to make them of commercial importance.

DISTRIBUTION.

NORTH CAROLINA.

There are a number of localities in North Carolina where the chrysotile variety of asbestos has been found, the most promising of which are in the vicinity of Glennville and of Sapphire, Jackson County; near the mouth of Squirrel Creek on North Toe River, along the western slopes of Rich Mountain in Watauga County; on Elk Creek in Ashe County; and near North Wilkesboro, Wilkes County. At these localities fiber of fair length and fineness has been found which warrant further investigation.

The deposit near North Wilkesboro is within three quarters of a mile of the railroad and occurs in a serpentine formation that is from 75 to about 200 feet in thickness and can be traced in a general N. W.-S. E. direction for nearly 600 yards. The deposit has been worked by means of an open cut 100 feet long which was made on the land of Mr. J. B. Church. The cut varies in depth from 1 to 35 feet and near the surface the serpentine encountered was much decomposed and altered, but at lower depths a compact, dark-green rock was found. This harder rock is similar to a bold outcrop of the serpentine that occurs on a low hill about 300 yards a little east of south of this cut on the land of Mr. G. W. Hinshaw of Winston, N. C. A similar outcrop of serpentine was observed on the summit of a hill 200 yards nearly north of the cut. In nearly all of this serpentine small seams of chrysotile asbestos were observed that varied in thickness from a quarter of an inch to nearly 2 inches, the thicker ones having been found in the bottom of the cut. These seams run at all angles through the rock, and as the unaltered serpentine was encountered, the quality of the asbestos became better. Sufficient work has not been done to demonstrate the value of this property as a source of asbestos.

Asbestos is found sparingly in all the enstatite rocks of this northeastern portion of the belt, but it is not probable that it occurs in quantity in these rocks. At many of the other peridotite outcrops besides those mentioned above, chrysotile of good fiber has been sparingly found, but there are no indications that it occurs in quantity. A fibrous enstatite and anthophyllite that closely resembles asbestos, have been found at a number of the corundum mines. It is, however, only the chrysotile asbestos found in these peridotite rocks that is worthy of investigation.

VERMONT.

The Vermont deposits are located in the northern-central part of the State, in the town of Eden, Lamoille County, and in the adjacent town of Lowell, Orleans County. The serpentine areas or belts extend for great distances to the north; but the existence of this serpentine is not indicative of the presence of asbestos; and up to the present time no definite discovery has been reported, except that in the belt on Belvidere Mountain, and even in this belt the asbestos is limited to a small area. There are two distinct varieties of asbestos in this belt. One occurs in veins that ramify through the serpentine in every direction. Its fibers are perpendicular to the walls of the seams, and have a maximum length, as thus far observed, of three-fourths of an inch, varying from this down to not more than one-sixteenth of an inch. It is similar in all respects to the Canadian product, and is just as good in quality. The other variety occurs upon the slickensided surfaces that are common in serpentine, and the fibers form layers of varying thickness against these surfaces, and have been found varying in length from a fraction of an inch up to 3 or 4 inches. These seams or layers of fibers are seldom over a quarter of an inch thick. The fiber is usually coarser than that found in the veins, and will not furnish so good a grade of asbestos.

ARIZONA.

The Arizona chrysotile asbestos deposits are located in the Grand Canyon of the Colorado River in Coconino County, on the north side of the river, about 70 miles a little west of north of Flagstaff, the county seat. The deposits are near the bottom of the Grand Canyon, about 4,900 feet below the rim. The asbestos occurs in the serpentinized portion of a dike of a basaltic rock. This dike is from 30 to 70 feet in thickness and along its contact with the sedimentary rocks where they are above or below or are included within it, is more or less altered to serpentine. It is partly in contact with limestone, conglomerate, and shales, and the greatest amount of serpentinization has taken place where this rock is in contact with limestone.

One noticeable exception to the usual occurrence of asbestos is the regularity of the seams. In some instances they are constant for a distance of 150 or more feet and then again, instead of a thick, massive serpentine containing numerous interrupted seams of asbestos, the Grand Canyon deposit is a thin body of serpentine containing but two or three prominent seams of asbestos which are, however, regular and nearly constant. The asbestos is of very good quality and equal to the Canadian.

CANADA.

Nearly all the asbestos imported into the United States is obtained from Canada and is of the chrysotile variety. These deposits are associated with the basic magnesian rocks described in Chapter II as extending from northern Alabama in the United States northeast to the Gaspé Peninsula in Canada. There are three distinct districts, all in the Province of Quebec, from 60 to 100 miles south and southwest of Quebec. One is in the vicinity of Danville; the second is near Coleraine, Black Lake, and Thetford, about 30 miles northeast of the first; and the third is near Broughton, about 15 miles northeast of the second. All these deposits have good railroad facilities, those near Danville being on the Grand Trunk Railroad and the others on the Quebec Central. There is still another district, in the vicinity of Ottawa, where asbestos occurs in limited amount, but it has not assumed any importance as a producer of asbestos.

Intersecting the serpentine with which the asbestos is associated are masses and dikes of a granitic rock, and there is undoubtedly some relation existing between the asbestos and these dikes. In nearly all places where asbestos is being mined, small seams or dikes of the granitic rock were observed cutting the serpentine, on one side of which the serpentine is hard and compact and contains very few and small seams of the asbestos, while on the opposite side the serpentine is softer, less compacted, seamed, and in some cases has strong indications of a shearing movement. It is in this character of rock that the asbestos seams are the largest and most abundant. These seams are often cut off from the denser serpentine by a very sharp and distinct plane similar to a fault. The presence of these dikes of granitic rock would be sufficient to account for the cracking and fracturing of the original peridotite rocks, with, perhaps, a certain amount of shearing action. In the subsequent alteration of these rocks into serpentine, the fibrous or crystalline serpentine would be formed along these cracks and fractures by re-crystallization aided by aqueous reactions. Undoubtedly some chrysotile asbestos is formed by a shearing movement, which may be the case where the fibers are parallel to the sides of the seam. In most cases, however, the fibers are nearly at right angles to the sides, so that the mineral was probably formed as described above.

In this Canadian district, small granitic dikes may aid the prospector in following the asbestos, and where they outcrop on the surface they should be of great assistance in locating favorable places.

The seams of asbestos vary from one-sixteenth of an inch to rarely 3 inches in thickness. The fiber, which varies from one-half to 3 inches in length is put on the market as crude asbestos and is the profitable product of the mines. The percentage of this quality of asbestos in the rocks is variable, and from 30 to even 90 tons of rock have to be mined to yield one ton of crude asbestos. Besides this, there is more or less very short fiber that is milled and sold as mill fiber or paper stock. As such a very large percentage of waste rock has to be removed, it is necessary to economize in every way possible in the handling of this rock.

This asbestos is generally mined by open cuts or pits similar to those made in rock quarrying, the rock being worked out by benches as far as practicable. Drilling is done by steam or compressed air except in the smaller places, where hand drills are employed. Holes are drilled from 8 to 12 feet, and in blasting it is intended to thoroughly loosen and shatter the rock. After the blasting it is pried out with crowbars and the pieces containing asbestos are broken by means of heavy sledges and steel wedges to such sizes that the asbestos can be readily broken out with small hammers. In the smaller mines the waste rock and asbestos are removed by means of a derrick, but in the larger ones cables are used. The asbestos is then transferred to a drying room, and when dry, is hammered in order to separate as completely as possible all attached rock and also to separate the fibers. This material is divided into three grades, according to quality, which are known as No. 1, Crude; No. 2, Crude (white); and No. 3, Crude (red). It is shipped in bags of 100 pounds each. The remainder of the asbestos rock, which contains fibers from a minute fraction of an inch to about one-half inch in length, is treated in the mills and made into mill fiber or paper stock. This material is dried, crushed to the right degree of fineness, and then passes into the "cyclones" which effect a nearly complete separation of the fibers from the rock. The fiber is thrown on the separating sieves, from which it is drawn away by exhausts. The rock which during this process has been reduced to a sand, is ejected into bins. This still carries some asbestos and is now beginning to be used, being placed on the market as asbestic. The prices of these various grades of asbestos are about as follows:

No. 1, Crude asbestos	$150 to	$250	per ton.
No. 2, Crude (white) asbestos	75 to	125	per ton.
No. 3, Crude (red) asbestos	50 to	75	per ton.
Mill fiber or paper stock	20 to	40	per ton.
Asbestic	1 to	3	per ton.

GENTHITE (NICKEL ORE).

Analyses have shown the presence of nickel in many of the peridotites, and its presence is very apparent, for as these peridotites begin to decompose under the influence of atmospheric and other agencies, green nickel silicates are developed along the joints and fissures of the rock. These silicates are principally genthite and garnierite (see page 327).

At nearly all of the peridotite formations examined, nickel silicate has been observed, occuring in some simply as a stain on the rock, while at others it has been found in seams nearly half an inch thick. On account of their intense color, these seams are very conspicuous and often give to the rocks the appearance of containing a large quantity of the nickel minerals. They have attracted much attention, and at a number of places some prospecting has been done, as at Webster, Jackson County, where prospecting operations have been carried on to a considerable extent. Thus far, however, nothing that gives promise of importance as an ore of nickel has been discovered in North Carolina.

The localities where genthite has been observed in greatest quantity are just south of Democrat, and near Alexander, Buncombe County; at Webster, and near Balsam, Jackson County; and near Elf, Cherokee County.

Future developments may show that at some of these localities nickel occurs in sufficient quantity to make mining profitable, but although it has been shown to be widely distributed throughout the peridotite belt, no place has as yet been found where it was sufficiently concentrated to be classed as nickel ore.

SERPENTINE.

It has been stated under the head of "Alteration of the peridotites," page 118, that while it is rare in North Carolina and Georgia to find masses of this rock entirely altered to serpentine, yet there are a few that are thus changed. These deposits are massive, of a light to dark green color, and are in nearly every particular identical with those of Maryland, Delaware, and Pennsylvania, in the more northern portion of the peridotite belt. As far as can be judged without further development of the deposits, the serpentine is as well adapted to architectural purposes as that of the northern States. In these States it is quarried extensively for exterior as well as interior work, and a number of buildings in Philadelphia, Baltimore, and Wilmington are either wholly built or faced with serpentine.

The stone is soft and works easily, but at the same time is tough and wears well. It takes a fine polish, and the dark green and mottled varieties give a very rich effect, while the light colors, though somewhat peculiar, are not unpleasing. While it has been used as an exterior building stone, it is better suited and much more effectual as an ornamental stone, especially for interior decoration.

There are a number of outcrops of serpentine in Buncombe County, between Weaverville and Leicester, in a strip that crosses the French Broad River a mile above Alexander. The most favorably situated deposits are on lands belonging to Mr. W. L. Foster, 2½ miles from Olivette, a station on the Southern Railroad; and to Mr. W. E. Pounder, a short distance further southwest. The serpentine here is of first-class quality and should be of value for both exterior and interior work, and its nearness to the railroad affording good shipping facilities, makes this a most promising deposit for quarrying. Other deposits which are as large and of about the same quality are on Paint Fork of Ivy River, Madison County, and on Bald Creek, Yancey County; but these are at the present time too far from railroad transportation.

In Caldwell County, a compact serpentine of a dark rich green to almost black color has been obtained from near Patterson. The stone takes a good polish.

About 14 miles northwest of Raleigh, Wake County, on Barton Creek, massive serpentine of a pale green color occurs in a dike, averaging about 300 feet wide, which can be traced for nearly two miles, by nearly continuous outcrops. The most favorable exposures for quarrying are on farms belonging to Dr. A. J. J. Penny, Mr. Jesse Adams, and Mr. Joseph Tadlock. The stone is somewhat mottled with yellowish seams, but takes a good polish.

Another deposit that is worthy of investigation is the one in which asbestos occurs, near North Wilkesboro, Wilkes County (see p. 58). At the bottom of the cut made in prospecting for asbestos, the serpentine obtained was of good color, hard and compact, and took a good polish. It is within three-fourths of a mile from the Southern Railway, and waterpower is available for sawing the stone.

Thus far, no attempt has been made to utilize the North Carolina serpentine; but there seems to be no reason why the Buncombe County and Wilkes County deposits should not be worked with success. One of the Georgia deposits, at Holly Springs, Cherokee County, has been worked, and the beautiful decorative effect of the stone can be seen in the new Prudential building at Atlanta, Ga. When once this stone has begun to be used in this State, there is little doubt that the demand for it will be rapidly increased.

LIMONITE.

In the alteration and decomposition of the peridotites, limonite is one of the resultant products and, in some cases, though but rarely, it has assumed the proportion of an ore deposit. Where this is the case, it has been observed that it is associated with the serpentine in those formations where the original basic magnesian rocks have been completely changed to serpentine. Cellular quartz often accompanies the limonite and is nearly always ferruginous and at times resembles in appearance gossan to such an extent that many prospecting pits and trenches have been dug in exploiting these localities for copper. On Staten Island, New York, a bed of limonite which attained a thickness of 12 feet was found resting upon serpentine rocks. This deposit has been mined to some extent as an iron ore. In Middletown Township, Delaware County, Pennsylvania, limonite has been mined at several localities, but, as far as can be ascertained, it was not commercially successful.

Thus far in North Carolina no deposits have been discovered that have seemed to be of value as an ore of iron.

APPENDIX

BIBLIOGRAPHY OF AMERICAN PERIDOTITES, CORUNDUM, AND ASSOCIATED MINERALS.

The following list includes articles referring directly to North American peridotites and their alteration products, serpentine, talc, etc.; the minerals associated with them; the various occurrences of corundum, and its associated and alteration minerals. Not all American literature has been available, and hence the list is not complete, but it is believed to be practically so for North Carolina, and the eastern crystalline region in general.

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[1] Many references to foreign literature are given in the foot-notes of the preceding chapters and are not included in the bibliography unless they refer directly to American subjects.

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PLATES XXXV TO XLV WITH DESCRIPTIONS

PLATE XXXV.

Figure 1. Dunite from Shooting Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 18 diameters. Shows typical arrangement of skeleton magnetite with chlorite, surrounded by a corona of the latter. The rock is nearly fresh, showing some alteration to chlorite, but no serpentinization. Thin section No. C22.

Figure 2. Dunite, same specimen as Fig. 1. A photomicrograph in polarized light with crossed nicols, magnified 12 diameters. The three-ply vein consists of a felted aggregate of scaly chlorite in the middle, with somewhat fibrous magnesite and occasional chlorite laths on either side, separating it from the olivine of the rock. Thin section No. C22.

Figure 3. Dunite, one-half mile south of Shooting Creek post-office, Clay County, N. C. A photomicrograph in ordinary light, magnified 18 diameters. Shows an advanced stage of alteration to chlorite, which penetrates the olivine along the cracks, particularly those due to cleavage. Much of the resulting chlorite is lath-shaped. Thin section No. C35.

Figure 4. Dunite from Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 18 diameters. Shows serpentinization proceeding along the basal cleavage cracks of the olivine (right to left in the central grain), although the pinacoidal cleavage is much more highly developed. The rock is perfectly fresh, with the exception of a small amount of yellowish green serpentine, a little chlorite, and accompanying secondary magnetite granules. Thin section No. B8.

Figure 5. Dunite from Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 16 diameters. An advanced stage of alteration to serpentine, which is chiefly of a fibrous structure and set at right angles or in radial bundles upon the surfaces of the olivine. Boundaries of the original olivine grains are outlined by magnetite granules in the serpentine, and olivine fragments within these areas extinguish together between crossed nicols. A magnetite-chlorite aggregate appears at the lower right hand side of the field. Thin section No. B74.

Figure 6. Dunite from Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 16 diameters. Almost complete serpentinization; only a few central remnants of olivine remain, while heavy magnetite aggregates mark the boundaries and some of the cracks of the original grains. Chlorite-magnetite aggregates appear at the left and near the bottom. Thin section No. B47.

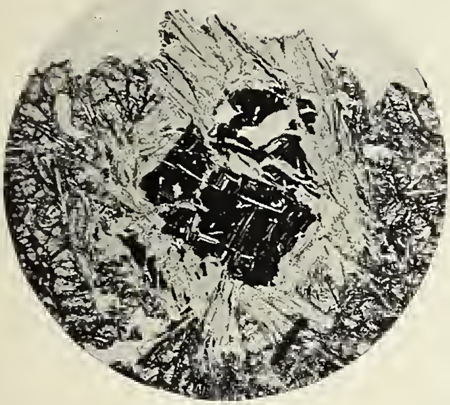


FIG. 1.

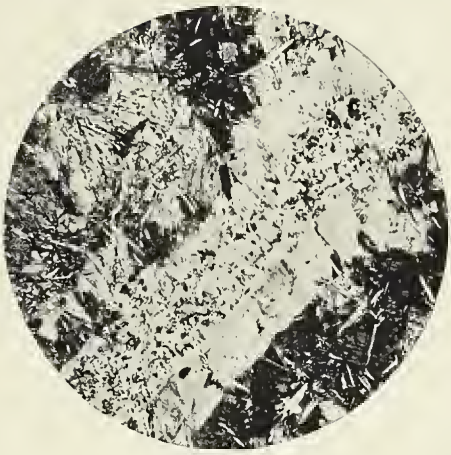


FIG. 2.

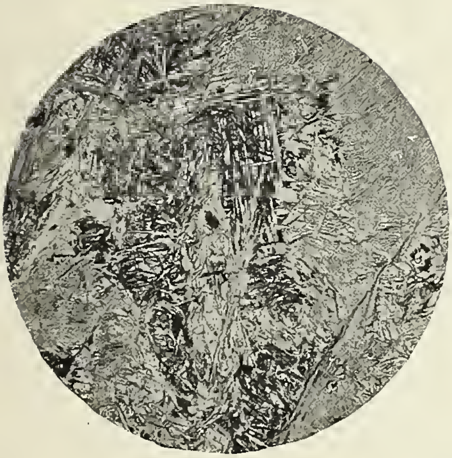


FIG. 3.

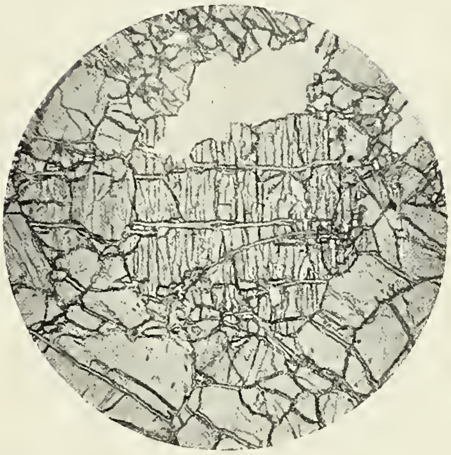


FIG. 4.

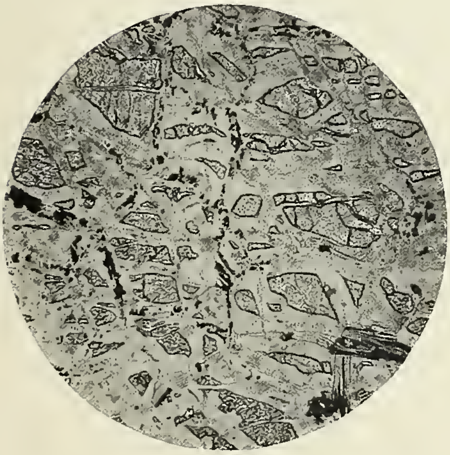


FIG. 5.

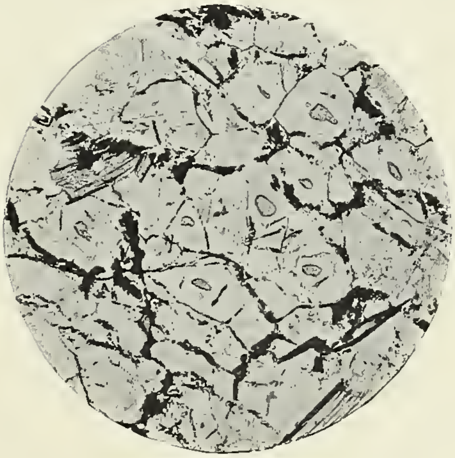


FIG. 6.

PHOTOMICROGRAPHS OF THIN SECTIONS OF PERIDOTITES AND RELATED ROCKS.

PLATE XXXVI.

FIGURE 1. Dunite from Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 12 diameters. Sheared and partially altered to green serpentine, especially along the parallel shear planes. The magnetite grains are accompanied by a little chlorite. Thin section No. B92.

FIGURE 2. Serpentine after dunite from Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 12 diameters. Shows characteristic grouping of magnetite masses in clusters of chlorite. Cracks and original borders of olivine grains shown by thin lines of oxide granules. Thin section No. B48.

FIGURE 3. Magnetite skeleton aggregates and olivine remnants from radial talcose sheaths formed along the joint planes of the dunite at Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 30 diameters. The lighter portions of the field are occupied by felted scaly talc, with occasional chlorite laths. A few small olivine remnants appear in high relief. Thin section No. B13.

FIGURE 4. Dunite from Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 16 diameters. A section from near the contact with troctolite, showing the yellowish brown, translucent chromite with irregular opaque borders due to loss of alumina in the formation of the surrounding chlorite. The olivine is slightly altered to yellow serpentine. Thin section No. B23.

FIGURE 5. Amphibole-peridotite from Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 16 diameters. Shows alteration of olivine to chlorite, which penetrates the grains, with more or less magnetite, chiefly along the cleavage. Thin section No. B72.

FIGURE 6. Amphibole-peridotite from Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 16 diameters. A chromite grain occupies the center of the field, surrounded by a large cluster of chlorite. Remnants of amphibole to the right of this are altering to chlorite. The olivine has altered slightly along the borders to dark yellow serpentine, full of oxide granules. Thin section No. B6.

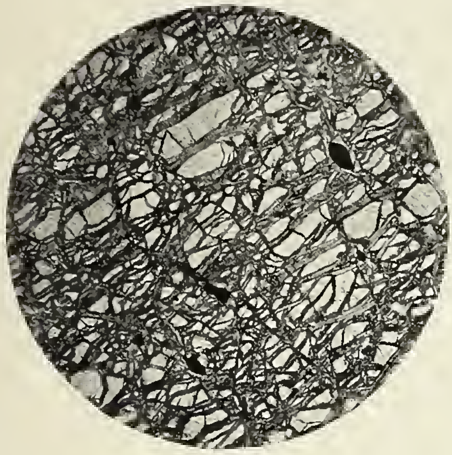


Fig. 1.

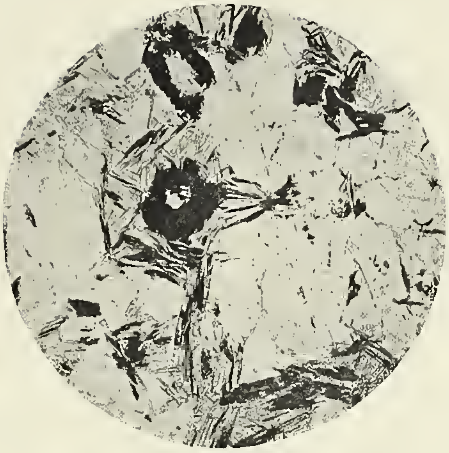


Fig. 2.

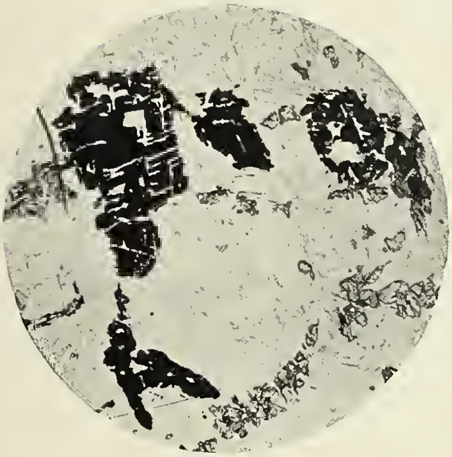


Fig. 3.

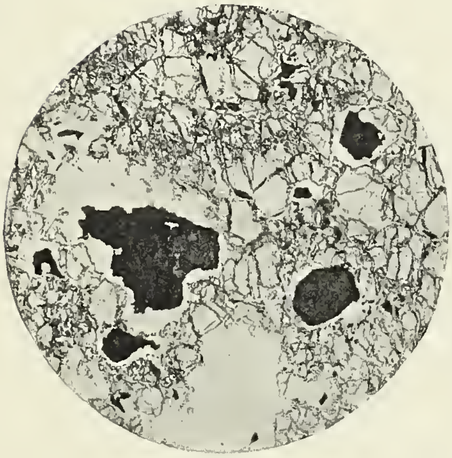


Fig. 4.

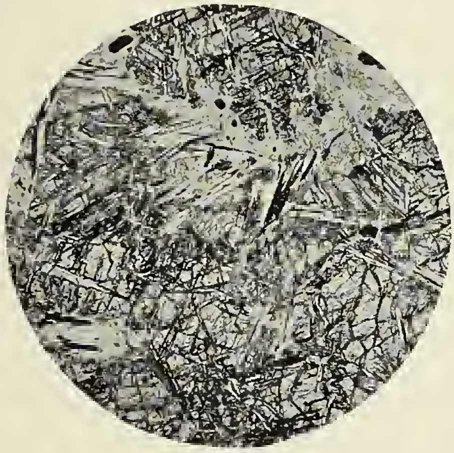


Fig. 5.

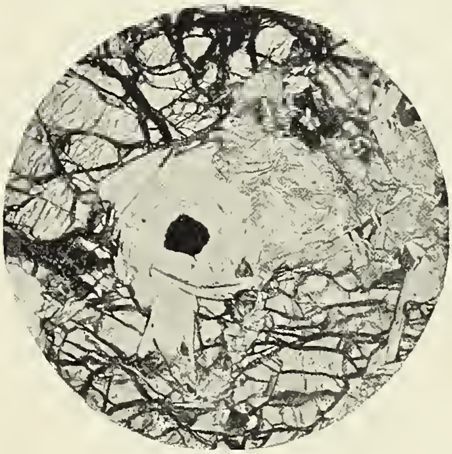


Fig. 6.

PHOTOMICROGRAPHS OF THIN SECTIONS OF PERIDOTITES AND RELATED ROCKS.

PLATE XXXVII.

FIGURE 1. Amphibole-peridotite from Buck Creek, Clay County, N. C. A photomicrograph in polarized light with crossed nicols, magnified 16 diameters. Shows twinning lamellæ in a large olivine grain, which is beginning to alter to yellowish serpentine in the cracks. Thin section No. B66.

FIGURE 2. Troctolite from Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 110 diameters. Shows a grain of spinel with yellowish brown picotite center which gradually passes into light green pleonaste toward the circumference. Thin section No. B25.

FIGURE 3. Amphibole-peridotite from Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 18 diameters. Shows incipient alteration of the amphiboles, which are crowded with black elongated granules of magnetite arranged parallel to the vertical axis. The olivine grains are irregularly cracked and are altering to yellowish serpentine and black oxide grains, with occasional laths of chlorite. Thin section No. B50.

FIGURE 4. Amphibole-peridotite, same as Fig. 3. A photomicrograph in ordinary light, magnified 110 diameters. Shows one of the amphiboles with the black inclusions more highly magnified. Thin section No. B50.

FIGURE 5. Troctolite from Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 14 diameters. Shows the development of chlorite in long curved laths in the large anorthite that occupies the middle of the field. The fibrous felted masses on either side of the anorthite are composed of actinolitic amphibole. Thin section No. B41.

FIGURE 6. Troctolite from Buck Creek, Clay County, N. C. A photomicrograph in polarized light with crossed nicols, magnified 14 diameters. Another mode of alteration of anorthite to chlorite, which in this case forms felted scaly aggregates that encroach somewhat uniformly upon the feldspar. Thin section No. B41.

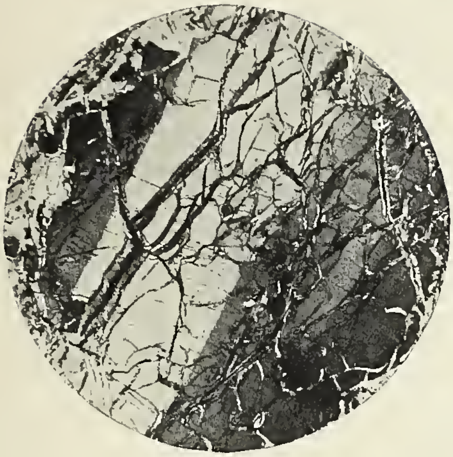


FIG. 1.

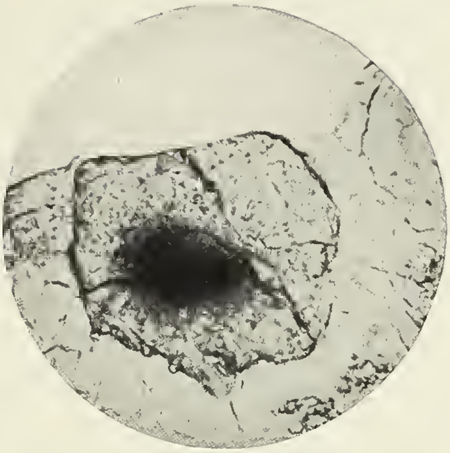


FIG. 2.

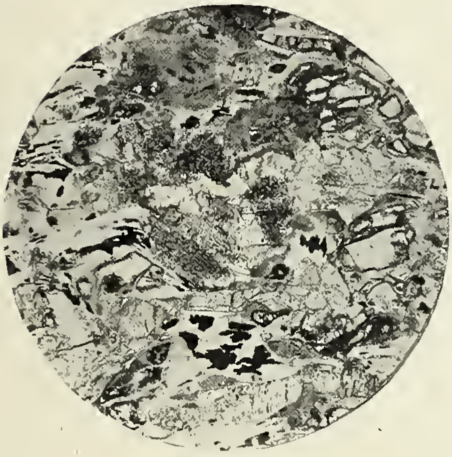


FIG. 3.

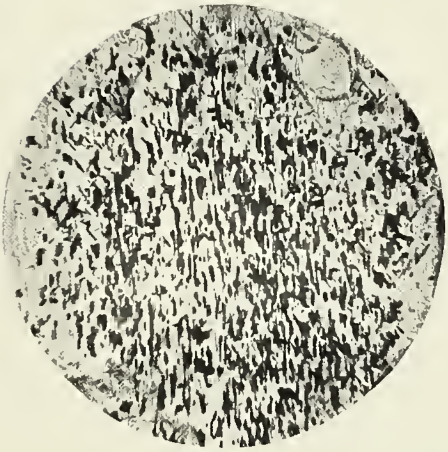


FIG. 4.

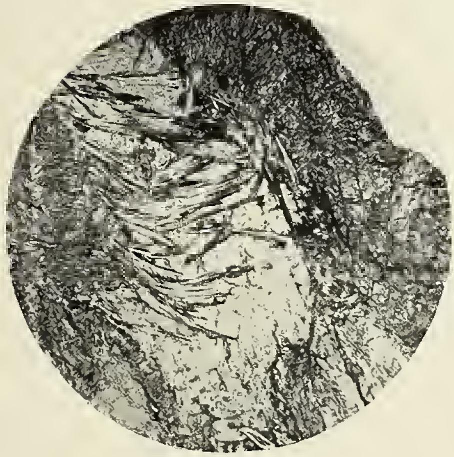


FIG. 5.

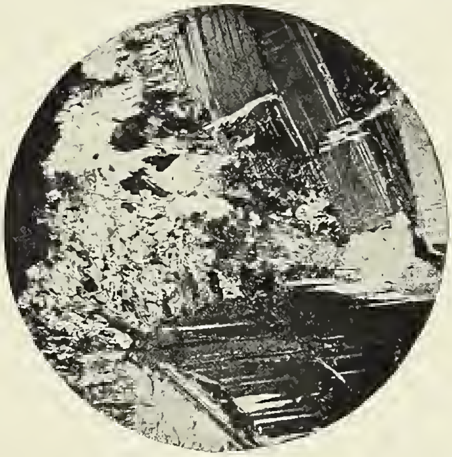


FIG. 6.

PHOTOMICROGRAPHS OF THIN SECTIONS OF PERIDOTITES AND RELATED ROCKS.

PLATE XXXVIII.

FIGURE 1. Dunite-troctolite contact from Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 14 diameters. Granular olivine of dunite occupies the left side of the field, showing only slight alteration to yellowish serpentine. On the right, the troctolite is represented chiefly by corrosion mantles of secondary minerals; olivine, similar to that of the dunite, is interspersed with these beyond the limits of the field. Thin section No. B24.

FIGURE 2. Troctolite from Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 14 diameters. Shows corrosion mantle between the olivine below and the anorthite above, partially enclosing an octahedron of yellowish-brown translucent chromite. The enstatite next the olivine and the diopside, forming a thinner middle layer, are so much alike as to be almost indistinguishable in ordinary light. The fibrous actinolite, intergrown with vermiculate pleonaste, forms a much thicker and darker layer next the feldspar. Thin section No. B56.

FIGURE 3. Troctolite, same as Fig. 2. A photomicrograph in ordinary light, magnified 14 diameters. Shows portion of a similar corrosion mantle much more highly developed. Olivine appears below, then follow the enstatite, arranged at right angles to the olivine surface, a thin layer of granular diopside, and a thick layer of fibrous actinolite intergrown with pleonaste, with anorthite above. Thin section No. B57.

FIGURE 4. Troctolite, Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 12 diameters. Shows the preponderant anorthite and the consequent entire replacement of portions of the olivine by corrosion products. The lighter colored areas are anorthite. The brownish yellow picotite (or chromite) grains appear black in the photograph. Thin section No. B34.

FIGURE 5. Troctolite from Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 18 diameters. Shows preponderant olivine and the entire replacement of anorthite grains by clusters of corrosion minerals. The light irregularly cracked portions about the circumference of the field are olivine. Thin section No. B58.

FIGURE 6. Troctolite from Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 11 diameters. In the middle of the field a part of the actinolite next the anorthite is altering into chlorite. The vacant spaces above were occupied by olivine, which crumbled away in the preparation of the section. Just below the middle of the field, chlorite is also developing in the anorthite, at right angles to the cleavage. Thin section No. B38.

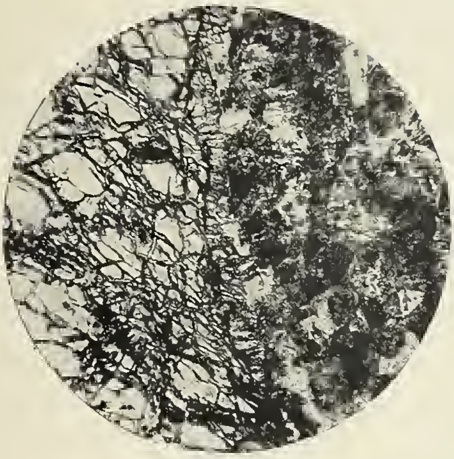


Fig. 1.

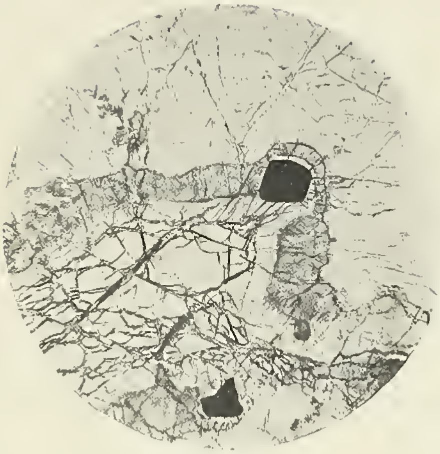


Fig. 2.

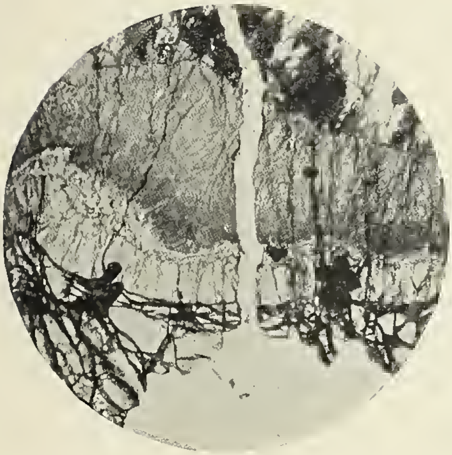


Fig. 3.

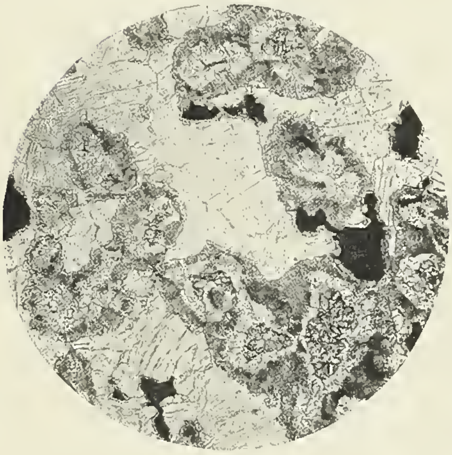


Fig. 4.

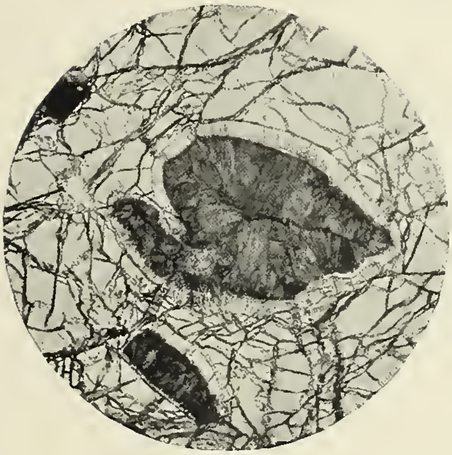


Fig. 5.

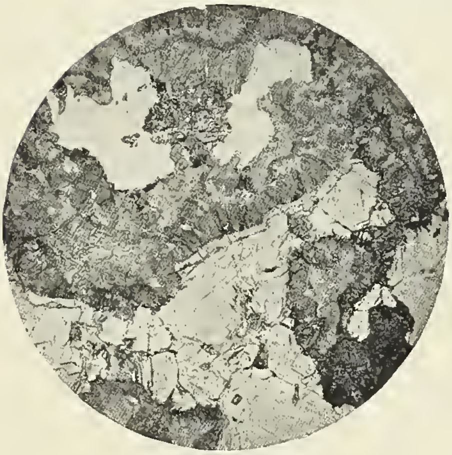


Fig. 6.

PHOTOMICROGRAPHS OF THIN SECTIONS OF PERIDOTITES AND RELATED ROCKS.

PLATE XXXIX.

FIGURE 1. Olivine-gabbro facies of troctolite from Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 11 diameters. In the center of the field anorthite grains are poikilitically inclosed in a large irregular augite. The latter is altered, with the exception of small iregular patches, into uralitic amphibole, with the formation of small greenish yellow rods and plates parallel to *c*. The corrosion products in the lower right and left sides of the field are chiefly fibrous and scaly amphibole intimately intermingled with irregular masses of pleonaste. Thin section No. B40.

FIGURE 2. Feldspathic or dioritic amphibolite from Buck Creek, Clay County, N. C. A photomicrograph in polarized light between crossed nicols, magnified 16 diameters. Shows the typical large feldspars and finely felted actinolitic amphibole. Much of the amphibole has been turned only slightly out of orientation by shearing, as shown by large basal and prismatic sections easily recognized in ordinary light. Thin section No. B52.

FIGURE 3. Amphibolite from Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 18 diameters. There is no feldspar. Much of the amphibole is thickly clouded by drop-like, rod-like, oval and rounded vermiculate inclusions of green spinel (pleonaste), in the central portions, while the borders remain free from inclusions. Two or three black-looking grains in the field are yellowish brown picotite passing gradually into green spinel on the borders. Thin section No. B36.

FIGURE 4. Amphibolite, Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 84 diameters. A large basal section of augite altering into amphibole occupies most of the field. An irregular oval remnant of augite occupies the central portion, and shows characteristic cleavage. Feldspars appear at the lower side of the field. Thin section No. B70.

FIGURE 5. Amphibolite from Buck Creek, Clay County, N. C. A photomicrograph in ordinary light, magnified 14 diameters. Four masses of corundum lie across the middle of the field. The three largest are pleochroic, light greenish yellow and purple, and are filled with grains and irregular masses of yellowish-brown picotite. Corundum above the largest of these grains, to the left, is without inclusions and lighter in color. Light green amphibole surrounds the corundum grains, except below the right hand grain and at the top of the field, where the amphibole contains picotite inclusions and is darker colored and pleochroic, sky-blue and yellowish green. Lighter areas above and below are feldspars. Thin section No. B2.

FIGURE 6. Amphibolite, same as Fig. 5. A photomicrograph in ordinary light, magnified 14 diameters. Shows one large grain of corundum filled with dark picotite inclusions, and a larger mass to the left of it free from inclusions. The latter shows rhombohedral parting and lighter colors. Light green amphiboles and colorless feldspars occupy the rest of the field. Thin section No. B2.

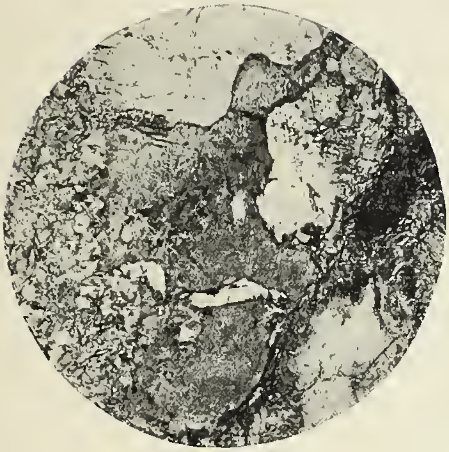


Fig. 1.

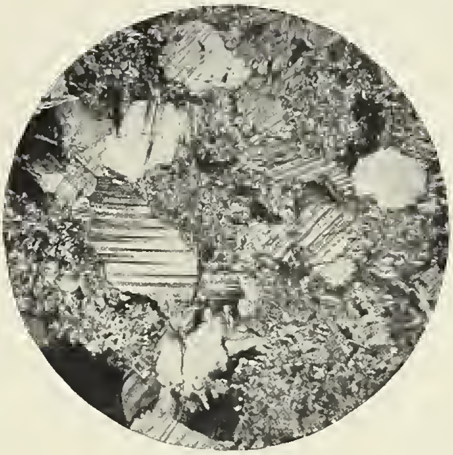


Fig. 2.

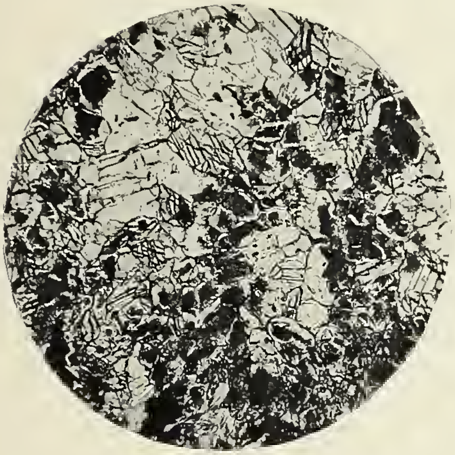


Fig. 3.

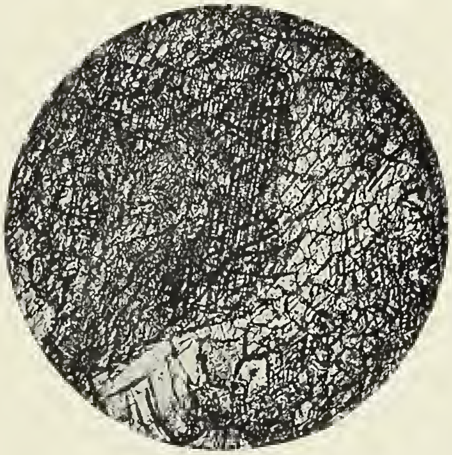


Fig. 4.

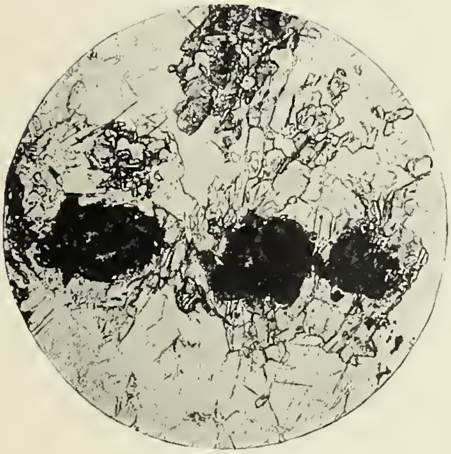


Fig. 5.

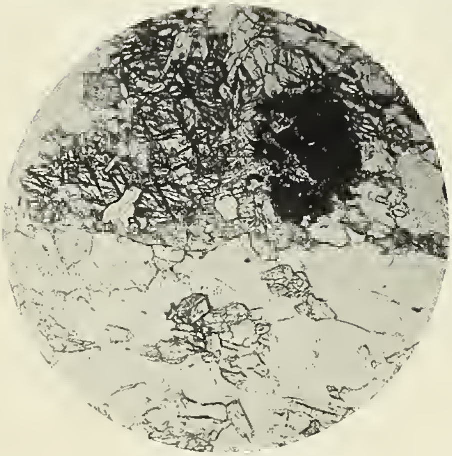


Fig. 6.

PHOTOMICROGRAPHS OF THIN SECTIONS OF PERIDOTITES AND RELATED ROCKS.

PLATE XL.

FIGURE 1. Dunite from Corundum Hill, Macon County, N. C. A photomicrograph in ordinary light, magnified 12 diameters. Section from a fine grained sheared rock, showing a large remnant of olivine with well developed cleavage in the lower part of the field. The upper half represents the granular condition of most of the section, the parallel arrangement of the granules and the development of serpentine being in diagonal planes rising from left to right. Thin section No. CH3.

FIGURE 2. Dunite from Corundum Hill, Macon County, N. C. A photomicrograph in ordinary light, magnified 16 diameters. Slender anthophyllite needles penetrate the rock in every direction. A section of an octahedral crystal of chromite appears at the bottom of the field. (Compare Pl. XLII, fig. 6). Thin section No. CH2.

FIGURE 3. Dunite from Corundum Hill, Macon County, N. C. A photomicrograph in ordinary light, magnified 18 diameters. Illustrates the structure of the laminated dunite; layers of fresh, granular olivine alternating with finer grained sheared portions. In this case the sheared layers are also considerably altered into serpentine. (Compare Pl. XLI, fig. 5). Thin section No. CH3.

FIGURE 4. Dunite, same as Fig. 3. A photomicrograph in ordinary light, magnified 40 diameters. Shows serpentinization of the shearing planes, one of which occupies the right half of the field, and the larger proportion of fresh olivine in the less disturbed layers. A flake of chlorite appears toward the left side. Thin section No. CH3.

FIGURE 5. Hornblende-granite from Corundum Hill, Macon County, N. C. A photomicrograph in polarized light between crossed nicols, magnified 18 diameters. Shows a large orthoclase in the center of the field, intergrown on the borders with finer grained minerals of later crystallization. Thin section No. CH8.

FIGURE 6. Hornblende-granite, same as Fig. 5. A photomicrograph in ordinary light, magnified 18 diameters. Shows hornblende crystals poikilitically enclosing numerous grains of other minerals. Thin section No. CH8.

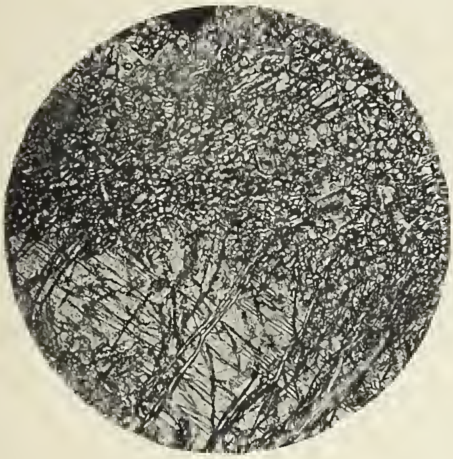
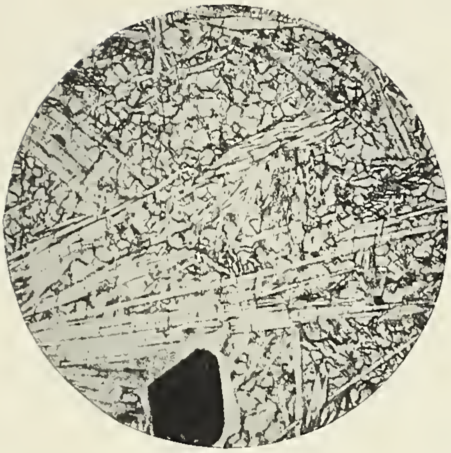


FIG. 1.



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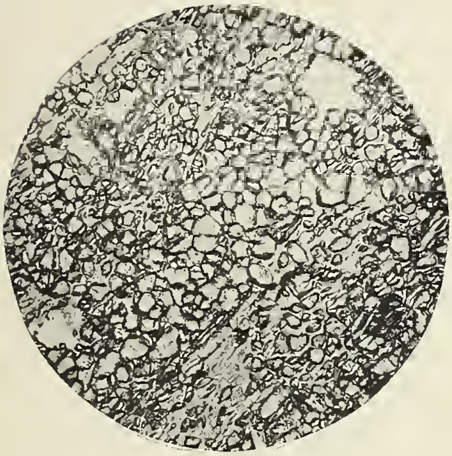


FIG. 3.

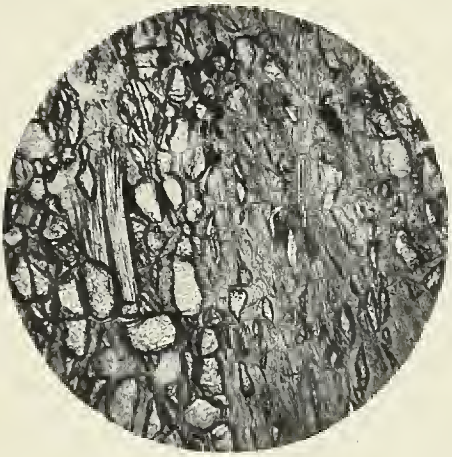


FIG. 4.

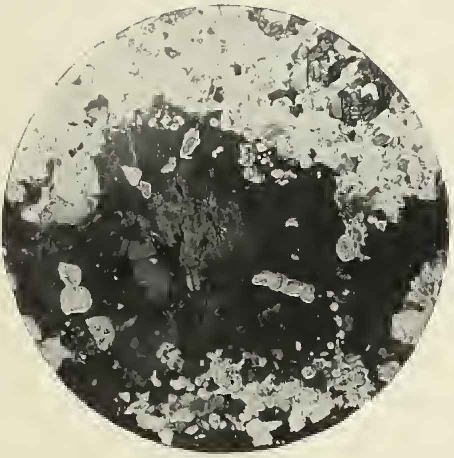


FIG. 5.

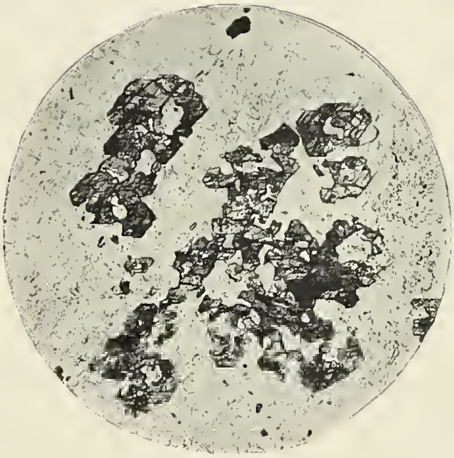


FIG. 6.

PHOTOMICROGRAPHS OF THIN SECTIONS OF PERIDOTITES AND RELATED ROCKS.

PLATE XLI.

FIGURE 1. Dunite from the Railroad cut 2 miles west of Balsam Gap, Jackson County, N. C. A photomicrograph in ordinary light, magnified 12 diameters. A typical granular dunite, showing only the slightest trace of alteration to serpentine. Thin section No. W11.

FIGURE 2. Dunite from Webster, Jackson County, N. C. A photomicrograph in ordinary light, showing the beginning of serpentinization along the borders of the olivine grains.

FIGURE 3. Dunite, Webster, N. C. A photomicrograph in ordinary light, magnified 18 diameters. Shows an advanced stage in the alteration of the olivine to serpentine. Some of the olivine grains are darkened on the borders by the segregated iron oxides. Thin section No. W1.

FIGURE 4. Dunite, Webster, N. C. A photomicrograph in ordinary light, magnified 18 diameters. Similar to Fig. 3, except in the larger amounts of the iron oxides segregated along the borders of the olivine remnants. Thin section No. W9.

FIGURE 5. Dunite from Cane Creek, 5 miles northeast of Webster, N. C. A photomicrograph in ordinary light, magnified 14 diameters. Shows the typical structure of laminated dunite, with alternating layers of sheared and unsheared granular olivine. Only a trace of serpentinization. (Compare Pl. XL, figs. 3 and 4). Thin section No. W23.

FIGURE 6. Dunite from 5 miles northeast of Webster, N. C., on the road from Webster to Hall. A photomicrograph in ordinary light, magnified 18 diameters. Shows dunite altered to chlorite in radiating tufts, with granules and irregular aggregates of magnetite. Small unaltered remnants of olivine are scattered throughout the field. Thin section No. W5a.

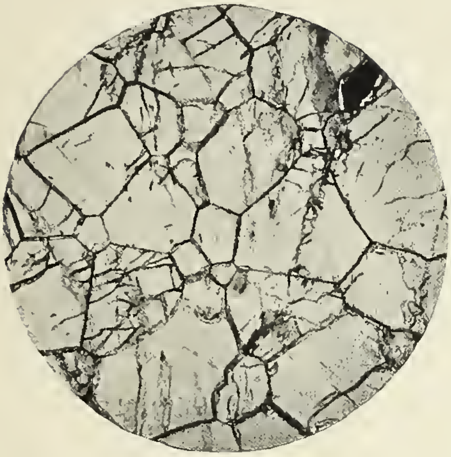


Fig. 1.

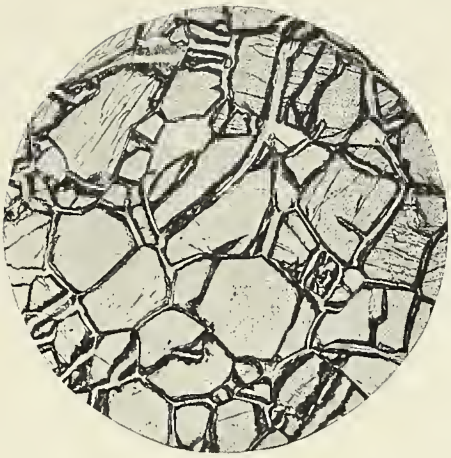


Fig. 2.

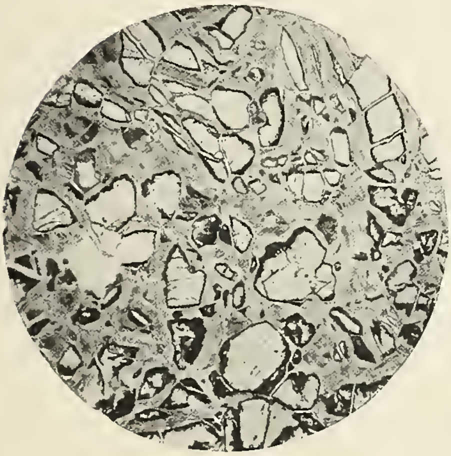


Fig. 3.

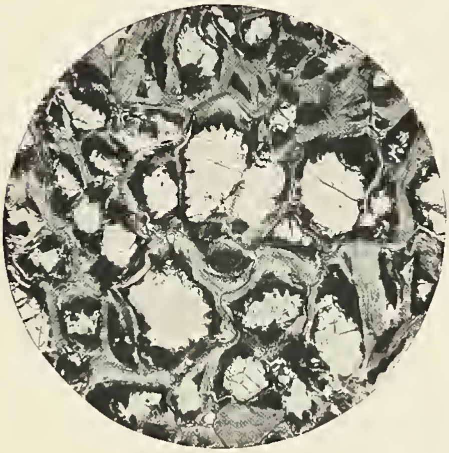


Fig. 4.

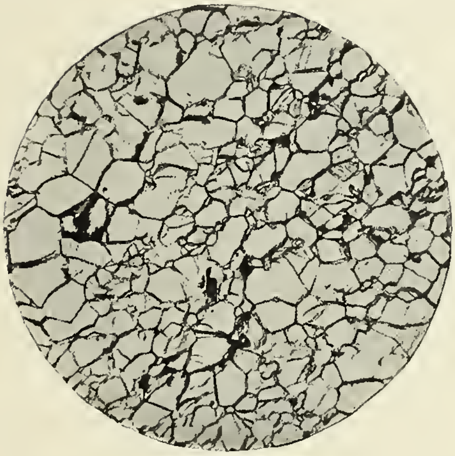


Fig. 5.

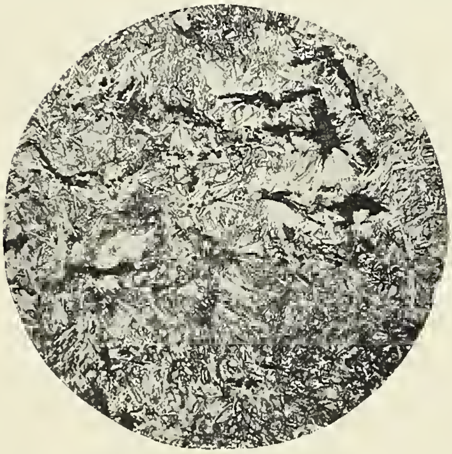


Fig. 6.

PHOTOMICROGRAPHS OF THIN SECTIONS OF PERIDOTITES AND RELATED ROCKS.

PLATE XLII.

FIGURE 1. Dunite from Webster, N. C. A photomicrograph in ordinary light, magnified 18 diameters. Shows large grains of chromite surrounded by coronas of chlorite. The olivine is beginning to alter along the borders to yellow serpentine. Thin section No. W4.

FIGURE 2. Dunite from Webster and vicinity, Jackson County, N. C. Parts of 4 photomicrographs in ordinary light, magnified 20 diameters. In the upper left hand quadrant, the interior portion of the large chromite grain crumbled away during the preparation of the section, showing the octahedral parting. The chromite grains in the other quadrants show various degrees of corrosion. Thin sections No. W4, W9, W22, W24.

FIGURE 3. Dunite from Webster, N. C. A photomicrograph in ordinary light, magnified 18 diameters. The large chromite in the center of the field includes grains of fresh olivine. The surrounding olivine is extensively altered to yellow serpentine. Thin section No. W9.

FIGURE 4. Websterite, from the type locality at Webster, N. C. A photomicrograph in ordinary light, magnified 10 diameters. Shows typical texture, large plates of diopside, and occasionally enstatite, scattered through a fine grained groundmass of the same minerals. The largest plate to the right is diopside, the smaller one to the left is enstatite. Thin section No. W2.

FIGURE 5. Enstatolite (enstatite-rock) from Webster, N. C. Parts of two photomicrographs in polarized light between crossed nicols, magnified 18 diameters. Shows characteristics of the coarse bladed rock. The left hand side shows the enstatite faulted across the cleavage; the right, a common columnar structure of the enstatite. Thin section No. W7.

FIGURE 6. Dunite from the Sapphire mine, Sapphire, Jackson County, N. C. A photomicrograph in ordinary light, magnified 18 diameters. Shows perfectly fresh olivine rock penetrated in every direction by slender needles of cummingtonite. (Compare Pl. XL, fig. 2). Thin section No. S3.

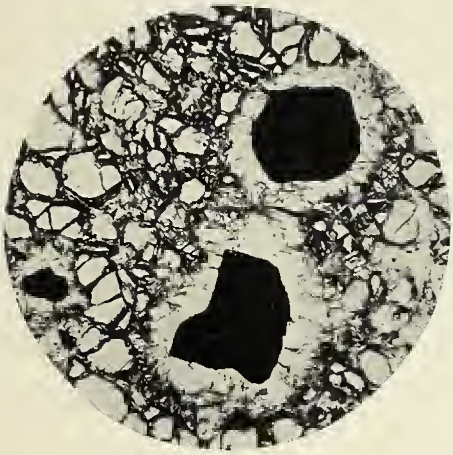


FIG. 1.

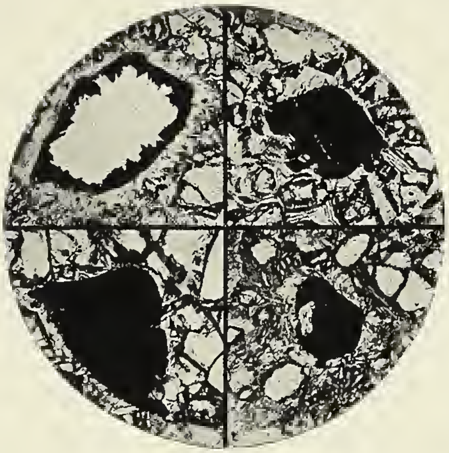


FIG. 2.

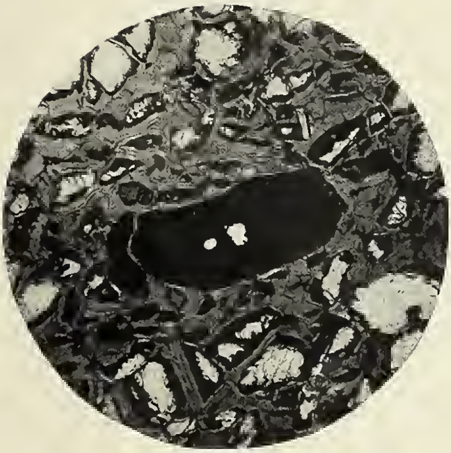


FIG. 3.

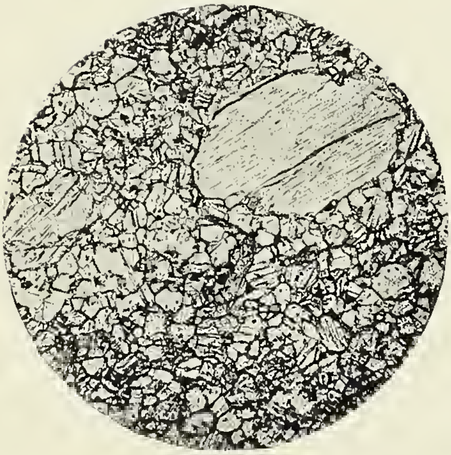


FIG. 4.

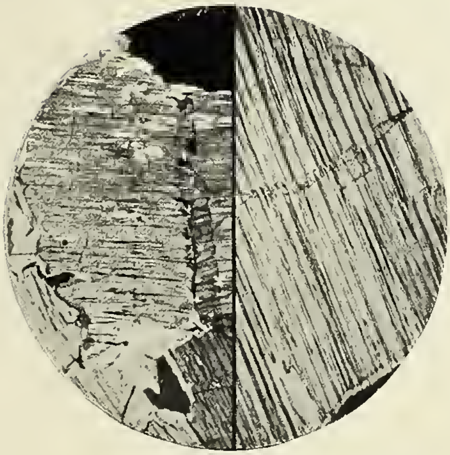


FIG. 5.

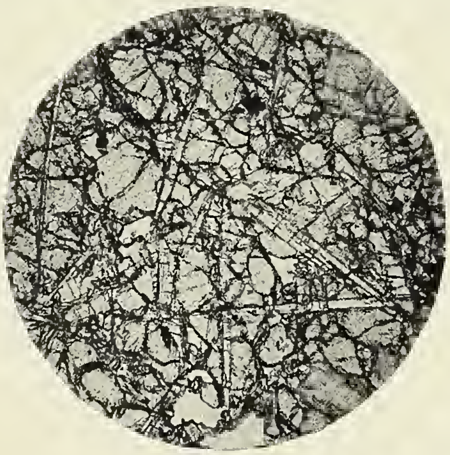


FIG. 6.

PHOTOMICROGRAPHS OF THIN SECTIONS OF PERIDOTITES AND RELATED ROCKS.

PLATE XLIII.

FIGURE 1. Dunite from the Carter mine, Madison County, N. C. A photomicrograph in ordinary light, magnified 16 diameters. Shows fine grained olivine with slight alteration to serpentine along the borders. The serpentine is filled with minute grains of segregated magnetite, so that the rock is almost black in the hand specimen. Thin section No. A25.

FIGURE 2. Dunite, same as Fig. 1. A photomicrograph of the same field in polarized light between crossed nicols, showing polarization of small grains together over large areas, representing the larger original olivine grains. Thin section No. A25.

FIGURE 3. Serpentine after dunite from 1 mile north of Weaverville and 3 miles east of Alexander, Buncombe County, N. C. A photomicrograph in ordinary light, magnified 18 diameters. Colorless and light yellowish serpentine, in which the outlines of the original olivine grains are preserved by lines of magnetite granules. The last altered remnants of olivine are represented by yellow central cores, which appear nearly black in the photograph. Thin section No. A17.

FIGURE 4. Serpentine after gedrite (or anthophyllite) from 2 miles southwest of Alexander and one-half mile west of the French Broad River, Buncombe County, N. C. A photomicrograph in ordinary light, magnified 18 diameters. Retains the original radiating bladed structure of the orthorhombic amphibole. Patches of opaque whitish, kaolin-like substance appear black in the photograph. Thin section No. A3.

FIGURE 5. Gedrite from Reems Creek three-fourths mile above its mouth, 1 mile southeast of Alexander, N. C. A photomicrograph in ordinary light, magnified 18 diameters. Shows the sheaf-like bundles of fibrous and bladed crystals. Thin section No. A10.

FIGURE 6. Gedrite, same as Fig. 5. A photomicrograph in ordinary light, magnified 12 diameters. Shows a part of the radial border of gedrite next the inclosing serpentine. Thin section No. A11.

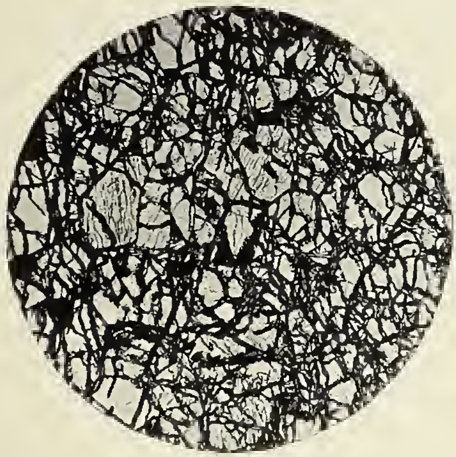


Fig. 1.

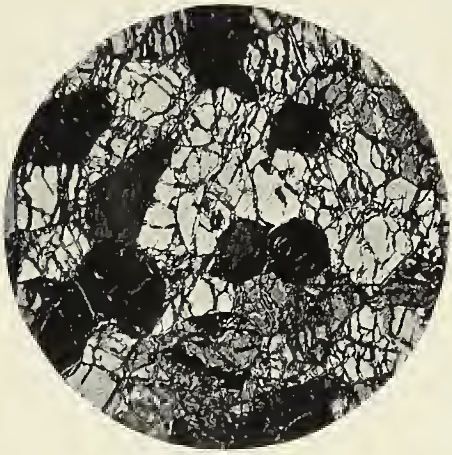


Fig. 2.

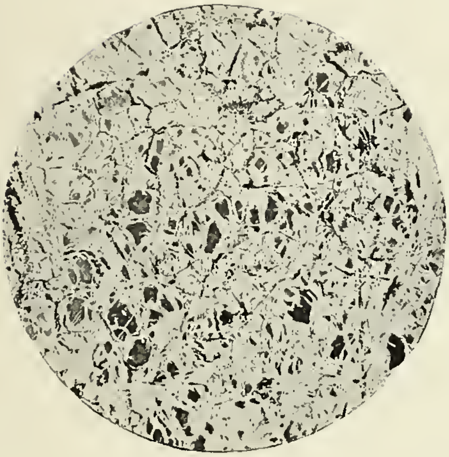
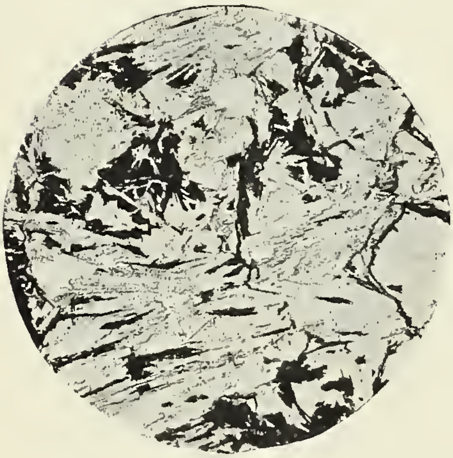


Fig. 3.



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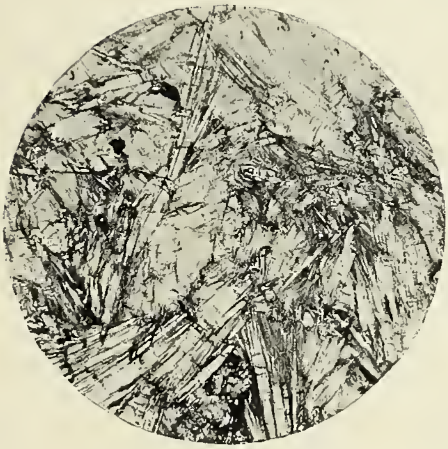


Fig. 5.

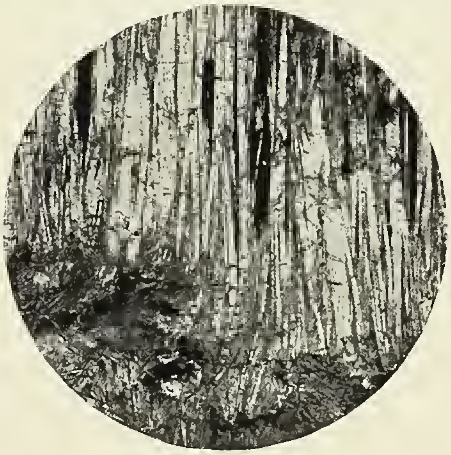


Fig. 6.

PHOTOMICROGRAPHS OF THIN SECTIONS OF PERIDOTITES AND RELATED ROCKS.

PLATE XLIV.

Figure 1. Dunite from Little Flat Creek, 1½ miles north of Weaverville, N. C. A photomicrograph in ordinary light, magnified 18 diameters. Shows an even grained sheared structure, somewhat in contrast with Pl. XL., figs. 3 and 4. and Pl. XLI, fig. 5. Thin section No. A21.

Figure 2. Serpentine after dunite from Newfound Creek, just below the mouth of Dicks Creek, 3 miles east of Leicester, Buncombe County, N. C. A photomicrograph in ordinary light, magnified 36 diameters. Shows a peculiar grouping of magnetite granules about a larger grain, suggesting the influence of magnetism. Thin section No. A4.

Figure 3. Mica-diorite from 3 miles southeast of Marshall, N. C., three-fourths mile northeast of the mouth of Ivy River. A photomicrograph in ordinary light, magnified 16 diameters. Shows large oval feldspar grains with small dark-green hornblende laths about their borders. The lower half of the field is chiefly biotite, with rounded grains of zoisite to the left. Thin section No. A40.

Figure 4. Serpentine after dunite, Paint Fork, Madison County, N. C. Parts of two photomicrographs, the left side in ordinary light, the right the same field in polarized light between crossed nicols, magnified 18 diameters. The darker spots in ordinary light are composed of honey-yellow serpentine clouded with magnetite granules, and represent the last altered cores of olivine. The light mesh-structure in polarized light shows the outlines of the original olivine grains. Thin section No. A31.

Figure 5. Anorthosite from the Hayes mine, north slope of Sampson Mountain, Yancey County, N. C. A photomicrograph in ordinary light, magnified 14 diameters. Shows zoisite and epidote crystals (indistinguishable in the photograph) scattered throughout the plagioclase. Thin section No. E7.

Figure 6. Anorthosite, same as Fig. 5. A photomicrograph in polarized light between crossed nicols, magnified 32 diameters. Shows a twin crystal of epidote in the center of the field. Crystals of zoisite appear above and to the left below. Thin section No. E7.

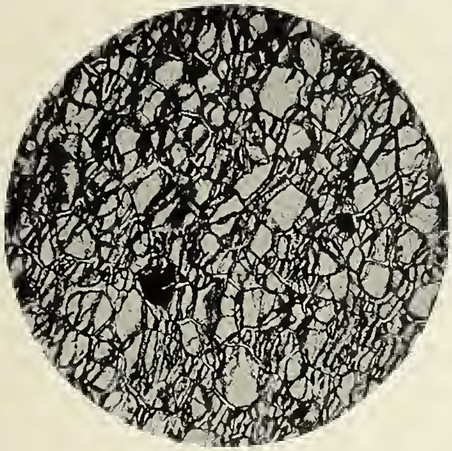


Fig. 1.

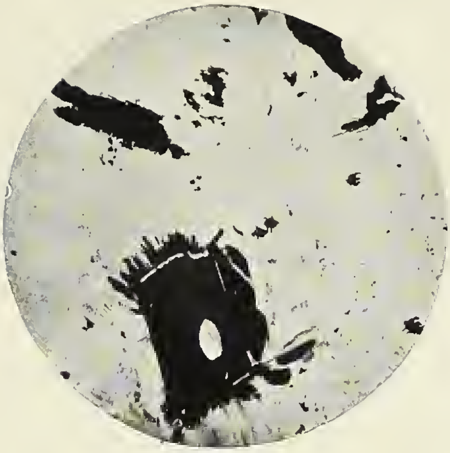
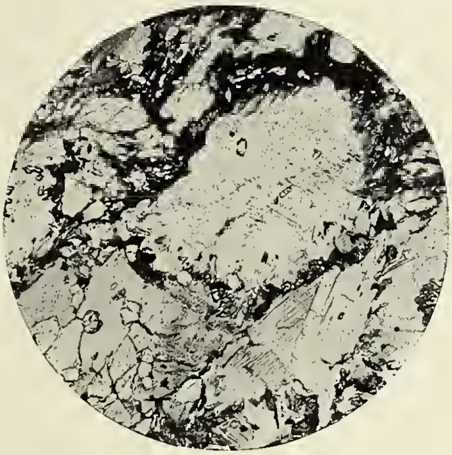


Fig. 2.



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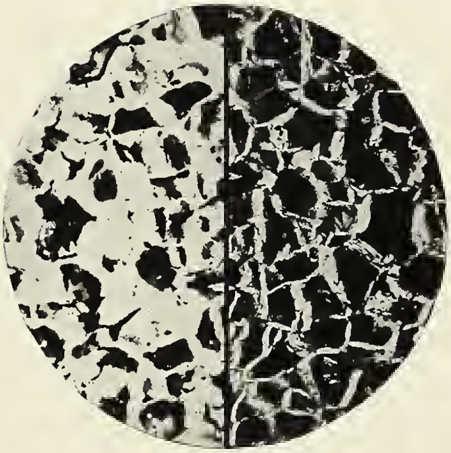
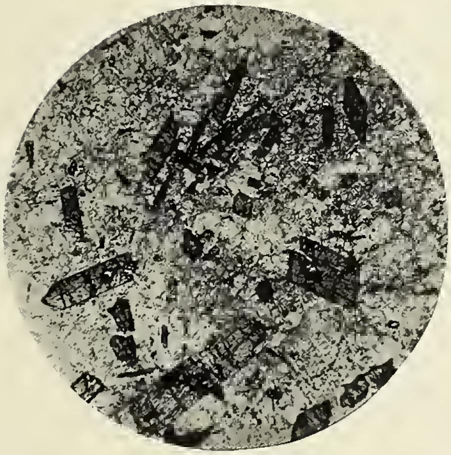


Fig. 4.



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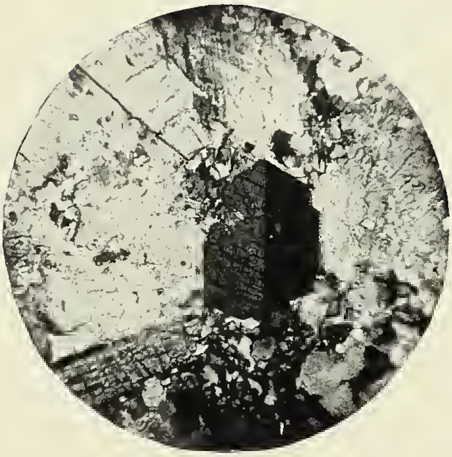
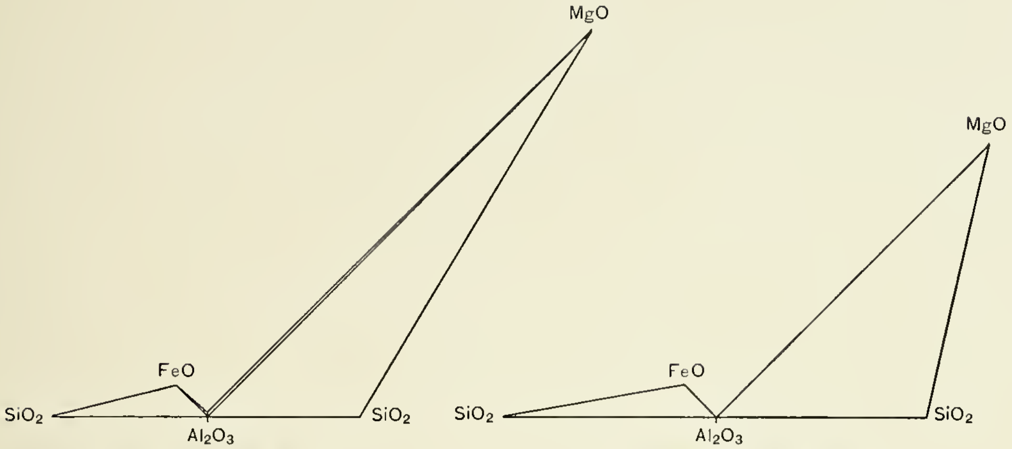


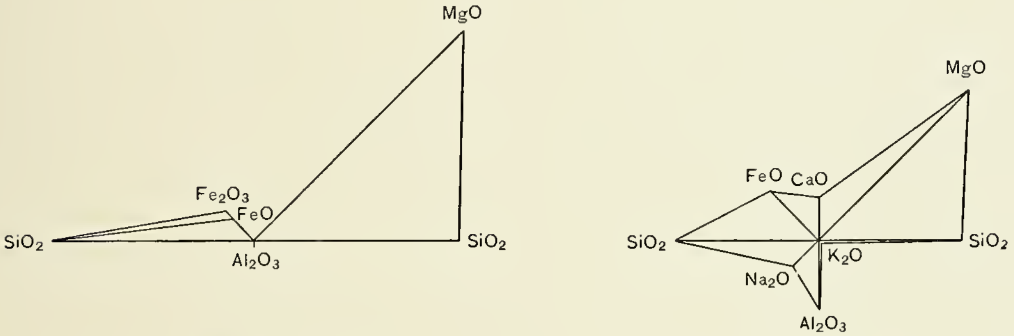
Fig. 6.

PHOTOMICROGRAPHS OF THIN SECTIONS OF PERIDOTITES AND RELATED ROCKS.



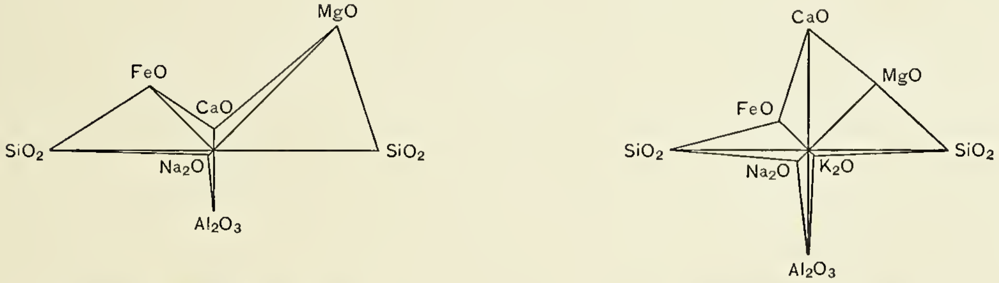
A. Dunite, Corundum Hill, N.C.

B. Enstatolite, Corundum Hill, N.C.



C. Websterite, Webster, N.C.

D. Troctolite, Buck Creek, N.C.



E. Amphibole-peridotite, Buck Creek, N.C.

F. Amphibolite, Buck Creek, N.C.

DIAGRAMS ILLUSTRATING THE CHEMICAL RELATIONS OF THE PERIDOTITES AND RELATED ROCKS.

(BASED ON MOLECULAR RATIO.)

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